Abstract

An Evaluation of the Limitations of the Technique of Dual Energy Absorptiometry in the Measurement of Bone Disease.

University of Glamorgan Mphil Thesis - Rachel Margaret Palmer - March 1996

Many osteoporotic bone fractures would be largely preventable if a screening programme were successful in identifying those most at risk or in the early stage of the disease. Assessment of bone mass by bone mineral density measurement has developed rapidly in the last 15 years from Single Photon Absorptiometry to Dual Photon Absorptiometry (DPA) and currently Dual X-ray Absorptiometry (DEXA). This study examines the results from patients scanned on both Novo Lab 22a (DPA) and Hologic QDR 1000 (DEXA) machines used at this hospital and gives a high correlation coefficient ($r = 0.96$, $p=<0.001$).

A comparison was made of previous studies on precision values. To convey the significance of patient's Bone Mineral Density (BMD) scans to the Clinician requires an accurate set of normal reference data. Several studies have indicated that international variations may be significant so a small local study was conducted to see if any trend were identifiable. In both male and female locals of the 70+ age group significantly higher values of BMD were found in the lumbar spine and all hip regions, producing 10-27% higher Z-scores. The percentage of the local population with undiagnosed, abnormal lumbar spine findings likely to effect the results of the

DEXA scans was studied. Of 500 sequential investigations, 100 subjects acted as controls. Of these 6% exhibited ambiguous results.Of the 400 clinical cases remaining, 19.25% produced complications in scan analysis.

Measurement of the hip may be open to greater errors in patient positioning than the spine and a study comparing standard scanning angle of the femur (20^0 internal rotation) to increases of 20^0 (40^0 internal rotation) and decreases of 20^0, 40^0 and 60^0 (0^0 rotation, 20^0 external rotation and 40^0 external rotation respectively) showed significant % increases. For femoral neck region the % change in BMD ranged from +2.77 to +9.23. For Ward's Triangle region increases were +3.79% (40^0 external rotation), +6.16% (40^0 int. rot.) and +8.05% (0^0rot.).

Where abnormalities exist and may be undetected, particularly in the older population, a trained operator may be needed to instigate radiographic backup. Patients with hip disease need particular care in positioning of the femur and further work is needed in designing a device to limit movement of the femur.

This study indicates that the limitations of the technique of Dual Energy Absorptiometry lie mainly in the comparison of clinical scans with normal data, correct positioning of the patient and well trained operating personnel to minimise the effects of artefacts and misleading results.

An Evaluation of the Limitations of the Technique of Dual Energy Absorptiometry in the Measurement of Bone Disease.

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Contents

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Declaration

This dissertation has not been, nor is being currently submitted for the award of any other degree or similar qualification.

Rachel Margaret Palmer

Copyright Statement

The work was carried out at The Royal National Hospital for Rheumatic Diseases, Bath.

In the Department of Clinical Measurement

Introduction

Osteoporosis is commonly defined as the loss of bone mass leading to an increased risk of accidental fracture. When bone density falls below a certain level, or fracture threshold, fracture risk increases from a minor trauma. In the past many physicians recognised that ageing bones became more susceptible to fracture. In 1941 Albright et al were the first to describe the clinical syndrome of osteoporosis, considering that it was caused by defective bone formation and was linked to the post menopausal state *(fig I.1)*.

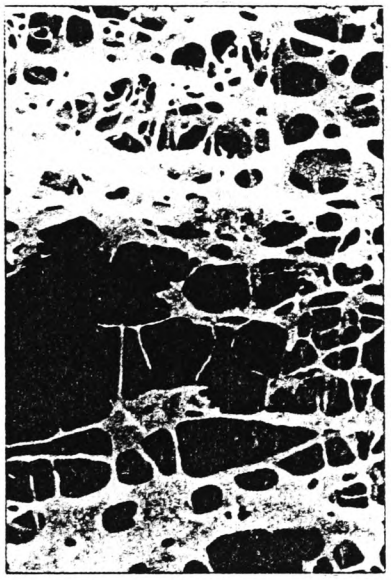


Figure I.1 Normal healthy bone Osteoporotic bone

(courtesy of Prof. A. Boyde, Hard Tissues Research Unit, University College, London).

Osteoporosis is estimated to cost the National Health Service (NHS) in the region of £200 million in operative and post operative care each year (Griffin, 1990; Wallace, 1987) following serious fractures. Life expectancy is increasing

in most parts of the developed world and with the increase in ageing population comes an increase in the incidence of osteoporosis related fractures.

There are many factors which influence the risk of developing osteoporosis, including race (Trotter et al,1960; Matkovic et al, 1979; Reid et al,1986; Sadat-Ali et al,1996), small body build, lack of or excessive exercise (Snow-Harter et al, 1992; McCulloch et al ,1990; Drinkwater, 1984; Lanyon, 1984), low calcium diet (Matkovic et al, 1979; Sandler et al, 1985), smoking (Baron, 1984; Mazess & Barden, 1991) and high alcohol consumption. However, by far the most important factor is post menopausal oestrogen deficiency in women (Geusens et al 1986; Riggs et al, 1981). As women can expect to spend a third of their lives after menopause and have a longer life expectancy than their male counterparts they are at greater risk and have a higher incidence of osteoporotic fracture.

There are many clinical conditions which heighten to the risk of bone fracture including vertebral deformity, oestrogen deficiency, long term glucocorticoid therapy and anorexia nervosa. Even minor trauma may lead these patients to develop bone fracture which, if present in the spine, may remain undetected for some time, until deformity leads to the onset of pain. Fractures occur most commonly in the wrist, spine and neck of femur (leg bone) of those with osteoporotic bone, although any bone is more susceptible to fracture than that of a non-osteoporotic. The most expensive in terms of cost of treatment is the neck of femur. Recent estimates of the cost to the NHS in the UK of neck of femur fractures (commonly known as hip fractures) estimate a total annual figure of £160 million (DHS estimate, Royal College of Physicians 1989). The

costs include post-operative and social care. In 1985 there were 43,230 admissions to hospital in England for hip fractures with an average stay of 29.8 days (Griffin,1990).

These fractures from excessive bone loss present a major health and social problem which is largely preventable, but this necessitates an accurate means of screening the population to predict those most at risk. The technology for quantitative measurement of bone calcium is relatively recent but developing rapidly. The most widespread technique in use is dual energy absorptiometry.

The aim of this study is to examine the limitations of in vivo bone mineral measurement by Bone Densitometry. To this end the available methods of measurement have been reviewed (Chapter 2), together with their limitations as identified by other authors. In Chapter 3 the principles of Photon Absorptiometry and dual X-ray absorptiometry (DEXA) are discussed and the results produced by the three major manufacturers of dual X-ray absorptiometers compared together with an appraisal of accuracy and precision errors identified by current studies.

The bone mineral density report must be able to convey the measured data of the area scanned and the implications of that result, to enable the Clinician or General Practitioner to make an accurate diagnosis and hence to treat the patient correctly (Chapter 4). This requires an accurate set of normal reference data for comparison. International variations in normal population results are under debate and a local study was undertaken by the author to examine trends in our area compared to the manufacturer's American data (Chapter 5).

Conditions affecting the lumbar spine and femoral neck do arise which may lead to scanning errors and which require intervention to a greater or lesser degree by the machine operator and involve the personal judgement of that operator. In Chapter 6 the author has given proposals to reduce these errors, illustrated by examples from a study of 500 consecutive lumbar spine scans in which the author was involved.

The author has drawn conclusions indicating the importance of awareness of these limitations and the further work needed to reduce their effects.

Chapter one

Chapter 1. Bone.

Bone is a highly specialised tissue consisting of fibres of connective tissue embedded with numerous minerals, including calcium, phosphorus and magnesium. These combine together to give the skeleton its inherent strength in supporting the body and serve as a source of ions necessary for body tissue function. Bone is not a static material but is continuously being remodelled by specialised cells, the three main types of which are osteoblasts, osteocytes and osteoclasts.

Bone Cells.

These cells continually form and resorb bone tissue in the adult in dynamic equilibrium so that total bone mass remains constant. If the equilibrium is disrupted fractures of the bone can occur. Osteoblasts line the internal surfaces of most bone, except those undergoing resorption. In their inactive phase they are flat and spindle-shaped. When activated by parathyroid hormone or calcitonin they become larger cuboidal cells (*fig. 1.1*).

Figure 1.1 Osteoblasts on bone surface (Woolf and Dixon, 1988) .

These form bone by laying down collagen and mucopolysaccharides to form a matrix. This is then mineralised by the deposition of calcium, phosphate and magnesium (*fig.1.2*).

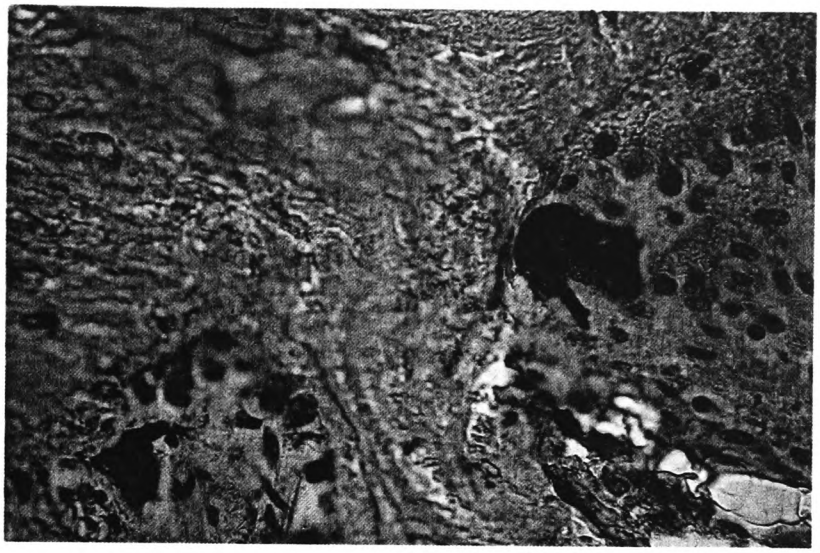


Figure 1.2 Bone cells (Woolf and Dixon, 1988).

Osteoblasts also synthesise many substances which regulate the rate of bone mineralisation e.g. alkaline phosphatase, prostaglandin E2.

Osteocytes lie in lacunae or spaces in the matrix and are derived from osteoblasts at the end of bone mineralisation. They have long processes by which they are linked to each other and it is believed that they play an important role in maintaining blood calcium levels (*fig.1.3).*

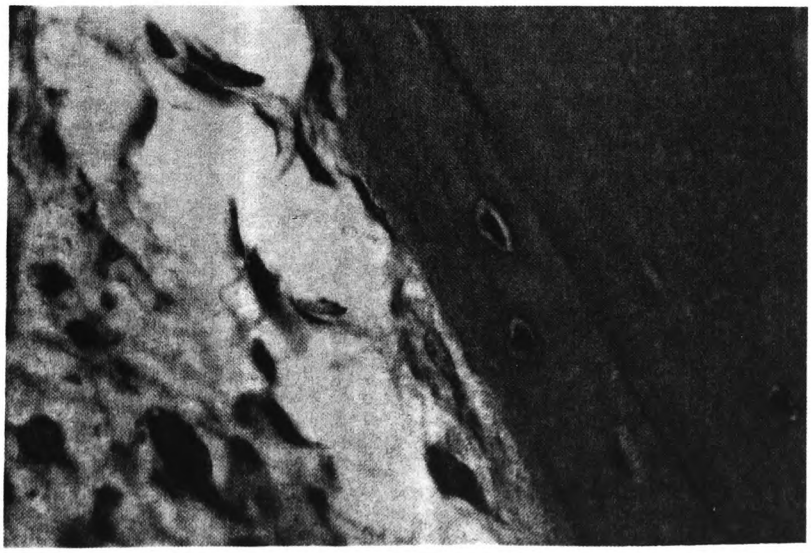


Figure 1.3 Flat layer of osteocytes on bone surface (Woolf and Dixon, 1988).

Osteoclasts are large cells with many nuclei. They are mobile and able to resorb calcified bone or cartilage. At the bone site they form a ruffled surface of microvilli which secrete acid and bone salts. These attack the bone to produce resorption pits known as Howship's lacunae (*fig.1.4).*

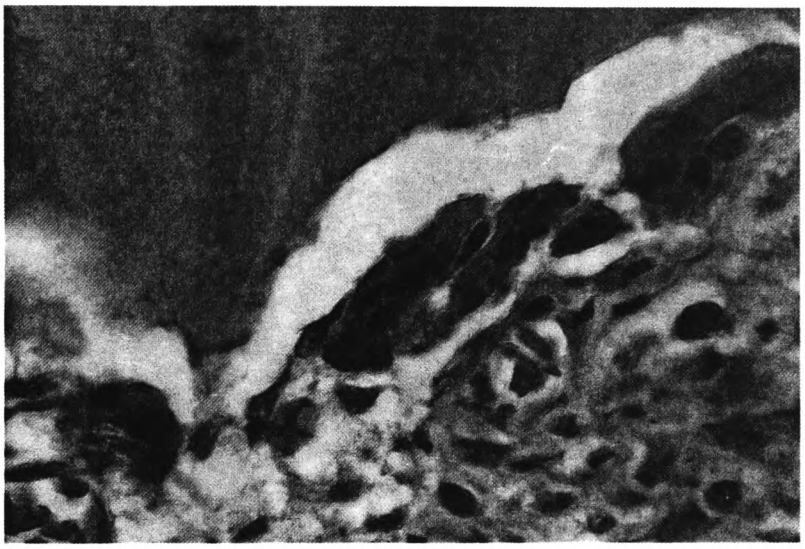


Figure 1.4 Osteoclasts and Howship's Lacunae (Woolf and Dixon, 1988).

Categories of Bone

There are two main categories of bone in the skeleton, weight bearing tubular bones and flat bones. These in turn have two main types of bone layer, cortical bone and trabecular bone.

Cortical or compact bone is hard surrounds all bone but is found in highest concentration in the shafts of the long bones. It consists of flat sheets or lamellae which form a tight spiral around a central canal through which blood vessels and nerves pass (*fig.1.5)*. These bundles are known as Haversian systems and they branch and communicate with each other allowing rapid movements of fluids for nutrition of the bone. Compact bone makes up 80% of body bone.

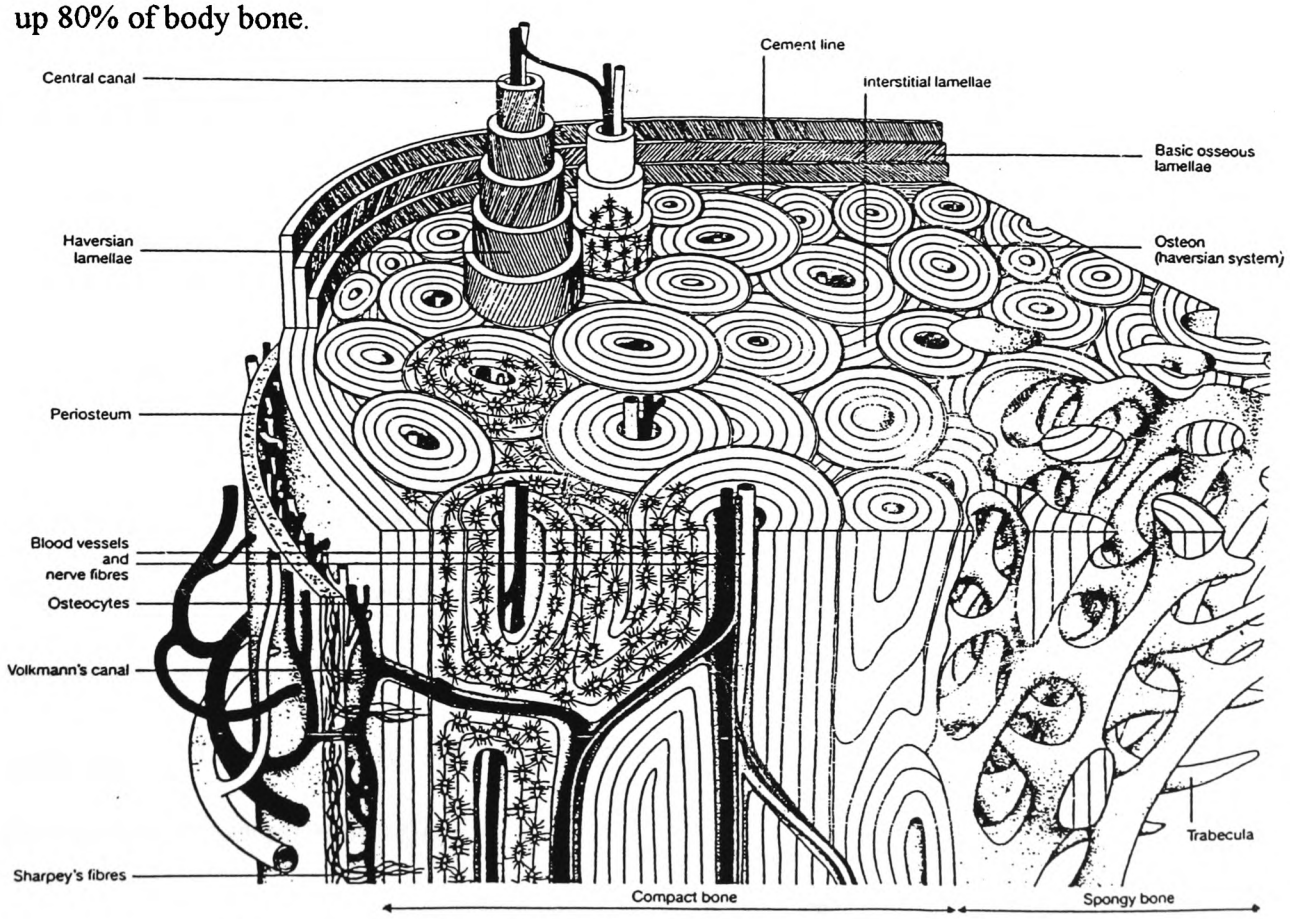


Figure 1.5 The structure of bone (courtesy of Sandoz Ltd).

Trabecular bone is a rigid, sponge-like mesh which gives bones stability and load bearing capacity. This network of interlacing partitions enclose the cavities of red or fatty marrow. Its large surface area allows high metabolic activity and acts as a calcium source. Trabecular bone makes up 20% of skeletal bone, forming the greater part of the spinal bones (vertebrae), most of the flat bones e.g. shoulder blade and pelvic bones, and at the ends of the long bones. Bone turnover is higher in trabecular than in compact bone.

Bone Formation

Bone is formed by osteoblastic mineralisation of collagen / mucopolysaccharides and also by the mineralisation of cartilage which is later replaced by bone. The skeleton of the foetus forms its general shape by the 26th week of gestation but it is not mineralised until much later. The foetus obtains these minerals from its mother and the bones continue to grow for the first two decades of life. Bone mass reaches its peak at the beginning of the third decade (Geusens et al, 1986) and the development of an osteoporotic fracture depends on the peak bone mass attained and, in later life, the bone mass lost. The lower the peak bone mass, the greater the risk of bone density falling below fracture threshold (Cooper et al, 1995). In the adult, bone is continually remodelled to allow for repair of injuries and for particular areas to strengthen if mechanical stresses are placed upon them. Remodelling of adult bone follows a sequence of activation, resorption, reversal, formation and mineralisation *(fig. 1.6)*.

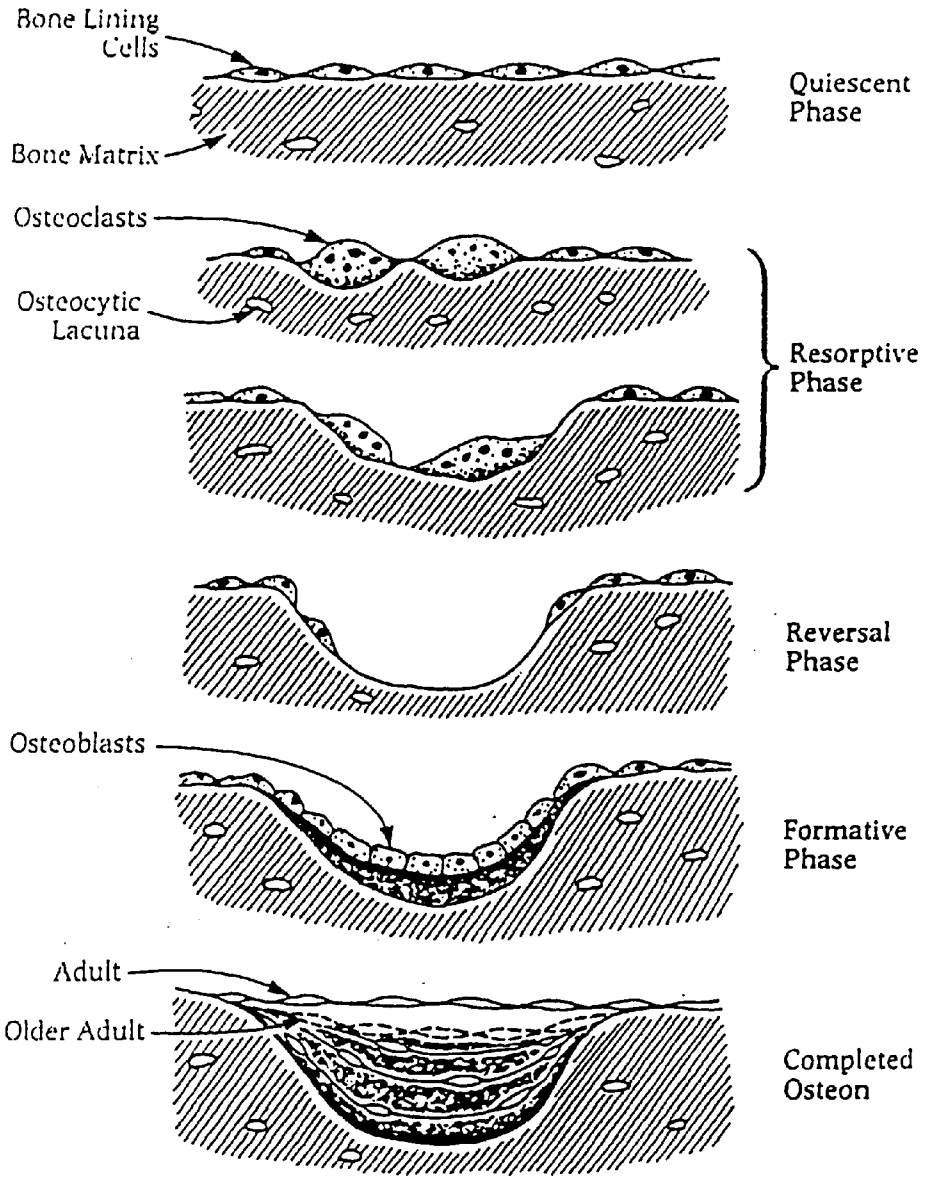


Figure 1.6. The remodelling sequence of Bone (Griffin, 1990).

Each phase has a specific time interval influenced by hormones, vitamin D metabolites and mechanical stress.

Bone Loss

Bone mass begins to decline after the third decade of life, (Riggs and Melton, 1986) initially at the same rate for men and women, but at menopause decreases sharply in women by up to 3% per year for the whole skeleton. As age progresses the loss in women gradually becomes less severe until by the age of 70+ it again matches the decline rate of men *(fig 1.7)* . This graph gives the impression that trabecular bone loss is linear. It is unlikely that in an individual loss would be that uniform but in cross-sectional studies this is the resulting pattern after reaching peak bone mass (Woolf and Dixon, 1988). Cortical bone production is increased by the surge of sex hormone produced prior to the attainment of peak bone mass.

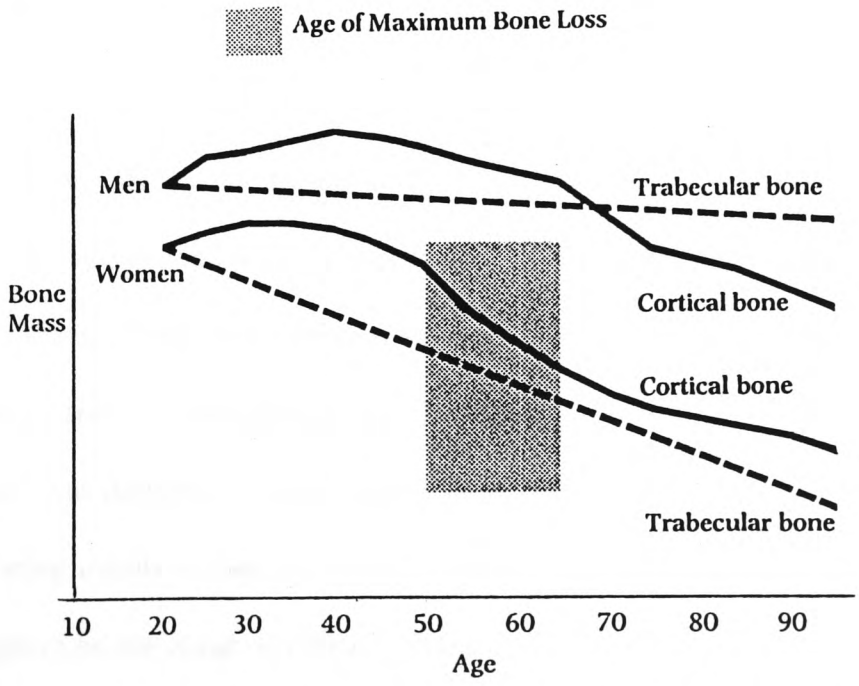


Figure 1. 7 Bone loss with age : a comparison of men and women

(Notelovitz et al, 1982) .

It has recently been postulated that the trabecular component of the lumbar vertebrae, despite being more metabolically active and making up 70-80% of the vertebral body, is not as important as was previously thought. Women lose about 35% of cortical and 50% of trabecular bone in their lifetime whilst men lose $^{2}/_{3}$rds of this. Vesterby et al (1991) support the view that the compact bone shell of the lumbar vertebrae contributes greatly to its strength.

This is important when considering osteoporosis therapy as some treatments e.g. sodium fluoride, increase trabecular bone mineral density (BMD) whilst decreasing compact bone (Dambacher et al, 1986). Substances which act positively on both trabecular and compact bone e.g. oestrogen and calcitrol, appear to reduce fracture rates (Dequeker & Geusens,1990). Calcitonin and Biphosphonates are under current study, having resorptive effects (Silbersten and Schnur,1992).

Although loss of bone mass is normal, accelerated bone loss and osteoporosis is not. In 1983 Riggs and Melton proposed two distinct syndromes of osteoporosis. Type I Osteoporosis being defined as occurring in a small subset of the population aged between 51 and 65 years of age and manifesting mainly as fractures of the forearm (Colles' fractures) and spine, caused largely by oestrogen deficiency post menopause. Type II Osteoporosis was defined as occurring in a large proportion of the 75 years + population and manifesting mainly as hip, humerus, proximal tibia, pelvis and spine fractures. These were thought to be the result of defective bone formation and increased bone loss from the influence of secondary hyperparathyroidism.

This division is highly debatable. There is considerable overlap in the risk factors for these sites and metabolic changes tend to effect trabecular bone more rapidly than cortical bone.

Chapter two

Chapter 2. Historical Review of Methods of Measurement.

Over the past 15 years there has been a rapid development in non-invasive techniques for quantitative measurement of bone mineral density. Originally radiographs were used to show simple changes in cortical thickness e.g. the metacarpal bones of the hand, using vernier callipers to measure the width of the medulla of the bone, and trabecular pattern grading (Singh Index). However, these required careful reproduction of the X-ray tube distance from the subject and subject positioning to avoid errors. Observer experience was also important. The method was also limited to peripheral sites of cortical bone.

Radiographic photodensitometry was used to compare the density of bone on the radiograph with that of a reference object of known density. However, variations in X-ray voltage exposure, non-uniformity of beam, scattering of radiation and selective beam filtration, and variations in film development limited the precision and accuracy of this method.

These methods were largely superseded by the development of photon absorptiometry, X-ray absorptiometry and quantitative computed tomography. Other techniques e.g. neutron activation analysis, Compton scattering, ultrasound, magnetic resonance and bone biopsy are also used but either do not have widespread clinical potential or are in the early stages of development.

Single Photon Absorptiometry (SPA)

Single photon absorptiometry was first developed by Cameron, Sorensen & Mazess in 1968 and can be used for measurement of bone mass in the peripheral skeleton . A low energy isotope source e.g. I^{125} produces a monoenergetic beam of photons which passes through the soft tissue and bone of the area to be examined. A scintillation detector situated opposite the source picks up any transmitted energy. Bone mineral content (BMC) is directly proportional to the attenuated beam in bone and soft tissue compared to that in adjacent soft tissue alone.

The soft tissue must be of uniform thickness and to assist this a water bath is used to surround the area to be measured. It also necessitates the measurement of peripheral skeletal sites e.g. radius and ulna bones of the arm and os calcis bone in the heel, where soft tissue cover is relatively uniform.

This method has the advantage of simplicity, is fast, inexpensive, and has low radiation dose (50-100μSv). Recent advances using rectilinear scanning and area density measurements have improved both precision and sensitivity of the method. It has been shown to identify elderly women at risk of fractures in the forearm (Wasnich et al 1985). However, the technique is limited to the peripheral skeleton which is largely compact bone. It has been shown that this less active bone does not necessarily mirror osteoporotic changes occurring in the spine and femoral neck. This makes it unsuitable for clinical diagnosis and monitoring of treatment in these areas. Several therapies

e.g. oestrogen hormone replacement therapy, can produce positive responses in the spine, but not in the appendicular skeleton (Dequeker and Geusens, 1990).

The development of Dual Photon Absorptiometry (DPA) also allowed assessment of the more active trabecular bone of the axial skeleton.

Dual Photon Absorptiometry (DPA)

Dual Photon Absorptiometry uses an isotope source with two different energies. This eliminates the need to have a constant thickness of soft tissue around the bone to be measured and allows measurement of other body locations (Nielsen and Krølner,1983; Wahner et al 1985). The influence of fat variations in the bone marrow on the measured bone mineral is reduced (but not eliminated) (Webber, 1987; Farrell and Webber, 1989; Goodsit, 1992). Initial sources used were a combination of I^{125} and Am^{241} in the USA and Sweden and Am^{241} and Cs^{137} in England. However, precision was found to be less than SPA so these were not particularly useful but did lead to the development of DPA using Gadolinium-153 (Gd^{153}) for measurements of spine and femoral neck. Gd^{153} emits X-rays at 44 keV and 100 keV, has a half-life of 242 days and the source lasts for approximately 12 - 18 months. It is expensive to replace. Radiation dose is still small, 10 - 50μSv.

Rectilinear scans produce bone mineral content equivalent to grams of hydroxyapatite (pure bone ash). Again BMC is obtained by subtracting attenuation of soft tissue from

that of adjacent bone and soft tissue. This method has high precision 1-4% reliant on exact relocation for reproducibility of repeated measurements.

As the activity of the source declines the absorptiometer must be carefully recalibrated. The disadvantages are cost of the machines and source replacements. The time for each measurement is 30 minutes, limiting population studies. However, advantages are low radiation dose and good accuracy and precision (Barden & Mazess, 1989).

Dual X-ray Absorptiometry (DEXA)

The dual photon absorptiometer has been modified by replacing the isotope source with an X-ray source (Verlaan & Piper, 1989). This source provided 500 times more photon flux than the Gd^{153} source used in the dual photon absorptiometer, allowing improved scan resolution (5 to 1.5mm). Analysis of data has been made more automatic by computer software update. This has greatly increased the speed and precision of technique (1%). The system alternates between low and high energy and between patient and reference measurements. The X-ray beam hardening is compensated for by the effect of soft tissue variations. External calibration is unnecessary. Scans take 10 minutes compared with 30 for the DPA. Radiation dose is lower as better beam collimation allows less overlap between scan lines. It is now also possible to assess the BMD of the entire skeleton.

Quantitative Computerized Tomography (QCT)

Computerized Tomography can be adapted to quantify bone mineral content of the vertebral body of the lumbar vertebrae using X-rays. The average density of the region to be measured is compared to that of calibration material (mineral equivalent phantom) exposed simultaneously or immediately after the patient. Bone content is expressed as trabecular bone density (TBD) in mg/cm^3 of K_2HPO_4 or calcium hydroxyapatite (Mazess, 1990; Barden & Mazess, 1989; Sambrook et al, 1985).

Technical limitations include effects of scattered radiation, beam hardening, scanner alignment and maintenance, positional reproducibility of patient and standard (Mazess, 1983; Genant et al,1982). Accuracy of assessment of vertebral bone mineral content is limited because of difficulty in discriminating attenuation between soft tissue and attenuating vertebral bones. This is thought to be due in part to increase in bone marrow fat, which has a low attenuation, with age. Osteoid formation will effect results. One advantage is the ability to discriminate between cortical and trabecular bone (Block et al,1989). QCT can measure trabecular bone with<=1% precision (Genant et al,1987). This should allow assessment of bone loss and the clinical affect of drugs (Genant et al,1987).

Radiation dose is high (up to 60 times that of DEXA) limiting use in serial measurements and in children. It is now possible to measure femoral neck sites with QCT using more advanced image processing techniques. Equipment cost is high and although scanners tend to be present in large centres for other purposes they are used full time, so elective tests for densitometry are limited (Barden and Mazess,1989). Also, values obtained from each scanner are unique and must be compared to normal values obtained thereon.

Peripheral QCT measuring forearm sites has been developed in Zurich (Reügsegger et al, 1990). This system is compact, inexpensive, easier to use and has a radiation exposure equivalent to DEXA (Grampp et al,1993). Reproducibility is<1% (Schneider & Borner, 1991) and can measure forearm in 2 minutes giving values for cortical and trabecular bone. As the equipment is more compact it is transportable and can be used at more than one site, being more cost effective.

Comparison of Methods of Measurement of Bone Mineral Content

SPA was thought to be of limited value in the diagnosis of osteoporosis at spine and femur sites as bone mineral loss in these areas is not reflected in the radius and os calcis of the appendicular skeleton. Only patients over the age of 65 years, where loss of bone from the appendicular skeleton matches that of axial loss can make use of this method. However, it is still used extensively in hospitals which cannot afford the more expensive equipment, e.g. Third World, Eastern Europe. More recently measurement of the forearm has been attempted using the more advanced DEXA equipment (Neer, 1992; Larcos & Wahner, 1991).

DPA shows for each 10% decrease in bone density there is a two- to threefold increase in the relative risk of fracture (Barden and Mazess 1989; Mazess,1990). In individuals, measurement at specific sites is the only way to identify fracture risk. DPA and DEXA can assess fracture risk and drug efficacy.

The introduction of DEXA has shown major advantages over DPA with increased resolution, higher quality images and better reproducibility achieved. Speed of scanning enables more patients to be measured over a given time span and precision is higher. The high cost of source replacement is eliminated. DEXA also allows total body composition to be estimated. One application is in the monitoring of anorexic or obese patients. A recent abstract (Adams et al, 1992) compares the use of SPA, DEXA and dual energy QCT of the spine on measurements of the spine and femoral neck. Data of local subjects in Manchester were compared to the American

reference data supplied. Correlation between measuring techniques varied between 0.49 and 0.76 and concluded that BMD measured by one technique could not be used to predict the BMD by another method in the same or different anatomical site. The table below (*table 1*) compares scans carried out at the most commonly used sites.

Table 1. **Comparison of bone densitometry techniques (Genant et al, 1990; Kalender 1992).**

Technique	**SPA**	**DPA**	**DEXA**	**QCT**
Site	Radius,Calcaneus (Integral)	Spine,Hip,TB (Integral)	Spine,Hip,TB (Integral)	Spine,Hip (Trabec/Integ)
Sensitivity*	1-2X	2X	2X	3-4X
Precision	1-2%	2-4%	1-2%	2-3%
Accuracy	5%	5-10%	4-8%	5-20%
Time	10-20min	20-40min	5min	10min
Dose	50-100μSv	50μSv	1-50μSv	100-10,000μSv

* Genant's subjective estimate of sensitivity refers to the capacity to separate an abnormal patient/population from a normal one by 1, 2, 3 or 4 times.

There are differing opinions on matters of tissue doses. All QCT cases require a chest X-ray the dose of which is included in this table. Should this be carried out routinely for the DPA/DEXA patients the doses quoted here would be higher.

Other Methods

Radioisotope scanning

Radioisotope scanning provides a functional assessment of bone. It works by using bone-seeking technetium labelled diphosphanates which are thought to be absorbed by the calcium of the hydroxyapatite crystal. It is a useful differential diagnosis rather than assessment.

Neutron Activation Analysis

This method works by bombarding the body with neutrons which convert stable calcium ^{48} to radioactive calcium ^{49}, which emits gamma rays. These rays can be detected to give a measure of total body calcium. Although precision can be up to 3% there is no way of determining the site of the calcium concentration, so it is not sufficiently accurate for osteoporosis determination, as these subjects may have calcified areas in their arteries.

The cost of this method is high in terms of the source of neutrons. The radiation dose is high (3000-15000 μSv). Neutron Activation Analysis was important in determining that total body calcium is higher in men than women, less in postmenopausal than premenopausal women and those subjects with particular clinical conditions, e.g. arthritis, but is not in general use for clinical diagnosis of osteoporosis.

Compton Scattering

Compton scattering is the beam of rays detected at right angles to an incident beam of photons. The intensity of this scattered energy is a measure of bone mineral content

and can be shown to be different in cortical and trabecular bone. It has been shown in a study of the calcaneus (heel bone), (Greenfield et al, 1988) which is 90% trabecular bone, that bone mineral density can be measured with an accuracy of 5% and precision of 3%.

Ultrasound

Broadband Ultrasound Attenuation (BUA) measures the attenuation of ultrasonic waves spreading through bone tissue. Attenuation through trabecular bone is greater than that through cortical bone. Velocity of sound is lower in the former. This is thought to be due to increased defraction of sound waves at the junction of trabecular bone and fat marrow (Bernecker et al 1990; Evans, 1988). In the latter study of a small number of patients a correlation was found between lower values of BMD in osteoporotic patients than in healthy controls in the calcaneus (13% lower) and values of BMD in the spine measured by QCT (30% lower). Most of the commercial systems available provide for measurement of the heel bone (os calcis) (Mazess,1992; Ramalingham et al,1992).

The method of measurement for the heel involves immersing the foot in a water bath. On one side of the heel is an emitting and detecting transducer. The heel is scanned in a trapezoid pattern at various frequencies (0.2 - 0.6 MHz) to produce a spectrum of energy versus frequency. This is compared to a reference spectrum obtained by scanning the water bath without the heel in situ (Baran et al, 1988). Positional problems have been recognised as a source of lower reproducibility, although manufacturers have their own recommendations for overcoming these problems. Foldes et al,1994 have devised a system requiring the operator to hold a sound head on the mid tibia through a layer

of gel, using the reflected sound signal as an index of bone quality. Another system uses a small hand jig to send a signal across individual fingers, the metacarpal joints of the hand and the distal radius (Gnudi,1995). Although BUA is a simple method of measurement and free from ionising radiation, the results at present do not have the accuracy of methods using vertebral sites. Other techniques have investigated the use of speed of sound (SOS) of ultrasonic waves compared to BUA (Rossman et al,1989; Zagzebski et al, 1991). It is not precise enough for diagnostic purposes but could be used for screening purposes, having the same area of precision as SPA and peripheral QCT. However, it has largely been superseded by the ability of DEXA machines to measure forearm and os calcis sites with half the precision error (Nielsen & Krølner, 1983). In large population studies it has been shown that there is good correlation with DEXA measurements of BMD but individual readings may not agree and there is speculation as to what is actually being measured.

It is now generally agreed that bone densitometry is the best procedure for predicting individual fracture risk and for identifying subjects at risk from osteoporosis (World congress on Osteoporosis: Hong Kong 1993) (Statement by British Chief Medical Officer of the Department of Health in 1994).

Chapter three

Chapter 3. Principles of Photon Absorptiometry.

Single Photon Absorptiometry.

A collimated I^{125} source (7.4 GBq) is scanned over the forearm and the transmitted beam intensity is measured with a scintillation detector *(fig.3.1)*.

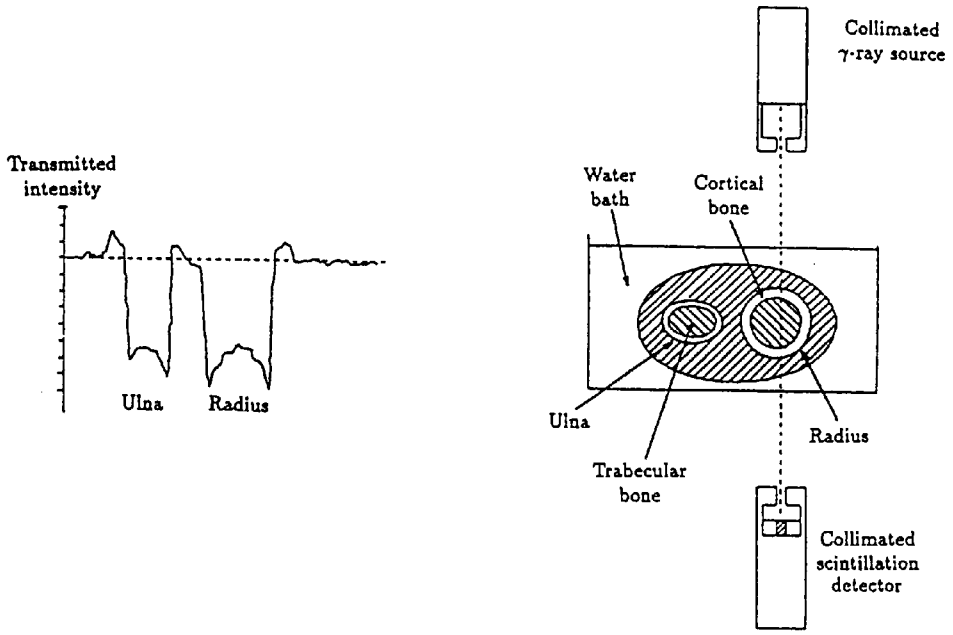


Figure 3.1 Schematic diagram of Single Photon Absorptiometer scanning forearm (Tothill, 1989).

$$\text{Bone Mass in photon beam path, Mb} = \frac{d_b \ln I_0 / I}{(u_b d_b - u_s d_s)} \ g/cm^2 \qquad (1)$$

I_0 =beam intensity after passage through tissue

I = beam intensity after passage through bone and tissue

u_b = attenuation coefficient of bone mineral in cm^2/g

u_s = attenuation coefficient of soft tissue in cm^2/g

d_b = density of bone in g/cm^3

d_s = density of soft tissue in g/cm^3

This equation (1) works on the principle that the soft tissue component remains constant (Cameron et al, 1968).

Dual Photon Absorptiometry.

Dual Photon Absorptiometry depends on the fact that bone and soft tissue have different radiation absorption properties (*fig 3.2).*

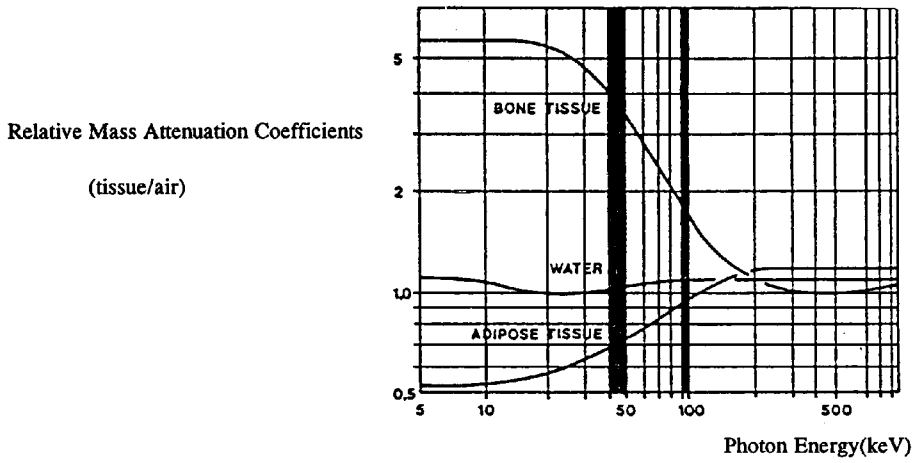


Figure 3.2 Variation in attenuating properties of bone, water and fat (Novo Lab 22A Operators Manual, Novo Diagnostic Systems, DK 2880, Bagsvaerd).

A radioactive source, most commonly Gd^{153} (55 GBq) transmits a beam of gamma photons, with two peak energies 44keV and 100keV, which is collimated then transmitted through the axial skeleton and is attenuated in proportion to the amount of soft tissue and bone in its path. Before scanning commences a value for attenuation through soft tissue alone is taken adjacent to the bone to be measured. By scanning rectilinearly across the body the attenuation of energy is measured at each point of measurement by a NaI detector. Total bone mass is the summation of the values at each point (Equation 2, Wahner et al, 1983; Valkemer et al, 1990).

$$\text{Bone mass at x,y} = \frac{\ln (I^{\circ}_{44}/ I_{44}) - (\mu_{s\,44}/\mu_{s\,100}) \times \ln (I^{\circ}_{100}/I_{100})}{\mu_{b\,44} - (\mu_{s\,44}\mu_{b\,100} / \mu_{s\,100})} \ g/cm^2 \qquad (2)$$

I° = Detected Intensity of beam attenuated by soft tissue only, measured at a point near the spine, I°_{44} in the 44keV channel and I°_{100} in the 100keV channel.

I_{44} and I_{100} are the measured photon intensities at point x,y.

$\frac{\mu_{s\,44}}{\mu_{s\,100}}$ = ratio of the attenuation of two photon energies in soft tissue.

$\mu_{b\,44}$, $\mu_{s\,44}$, $\mu_{b\,100}$ and $\mu_{s\,100}$= mass attenuation coefficients of bone mineral and soft tissue at low and high energies respectively (Wahner, 1983; Valkemer, 1990).

Dual Photon X-ray.

The radioisotope source is replaced by an X-ray source. DEXA machines base their algorithms on Equation 2 but must make allowances for the broader energy spectra of the X-ray tubes by rearrangeing it as follows:

$$M_b = k_1 \ln(I^0_{100} / I_{100}) + k_2 \ln(I^0_{44} / I_{44})$$

$$= k_1 \ln (I^0_H / I_H) + k_2 \ln (I^0_L / I_L) \qquad (3a)$$

where $_L$ = low energy spectrum peaks and $_H$ = high energy spectrum peaks

$$k_1 = \frac{\mu_{s\,L}}{(\mu_{s\,L}\,\mu_{b\,H} - \mu_{s\,H}\,\mu_{b\,L})} \qquad k_2 = \frac{\mu_{s\,H}}{\mu_{s\,H} - \mu_{s\,L}\,\mu_{b\,H}} \qquad (3b \text{ and } 3c)$$

(Equations 3a,b and c from Manufacturer's data, Norland)

Hologic consolidate this equation further :

$$Mb = kH - L \qquad (4)$$

where $H_{,} = \ln (I^0_H / I_H)$ and $L = \ln (I^0_L / I_L)$ (Verlaan and Piper, 1989). It is these constants which are determined by different methods by the separate companies.

Corrections are required for beam hardening and fat content etc and again the companies implement these differently.

Manufacturers of the X-ray bone densitometers also use different methods to achieve dual energy beams.

The ***QDR 1000 (Hologic)*** has a tungsten stationary anode X-ray tube pulsed alternately at 70 kVp and 140 kVp operated at a peak tube current of around 3mA. This produces effective beam energies of 43keV and 110 keV using 2mm aluminium and 1.6mm brass filters respectively *(fig. 3.3)*.

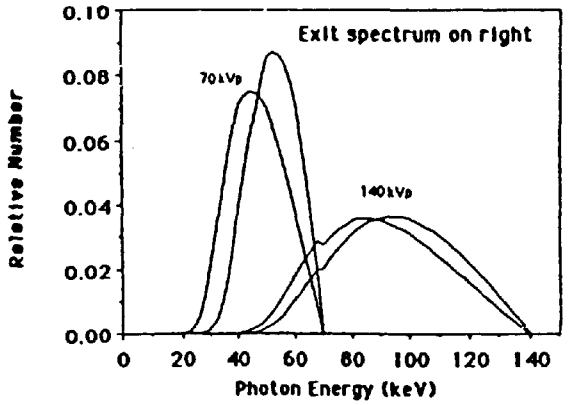


Figure 3.3 Calculated entry and exit spectra (Verlaan & Piper 1989)

The filters are mounted on a wheel which rotates synchronously with the voltage pulsing frequency. The detector is a cadmium tungstate scintillator coupled to an

integrating photomultiplier tube (rather than photon counting). There is an internal reference system *(fig.3.4)* providing pixel by pixel calibration using a rotating calibration wheel *(fig.3.5)* containing bone and tissue equivalent materials which compensates for variations due to fluctuations in X-ray beam characteristics and for beam hardening effects of soft tissue and radiation scatter.

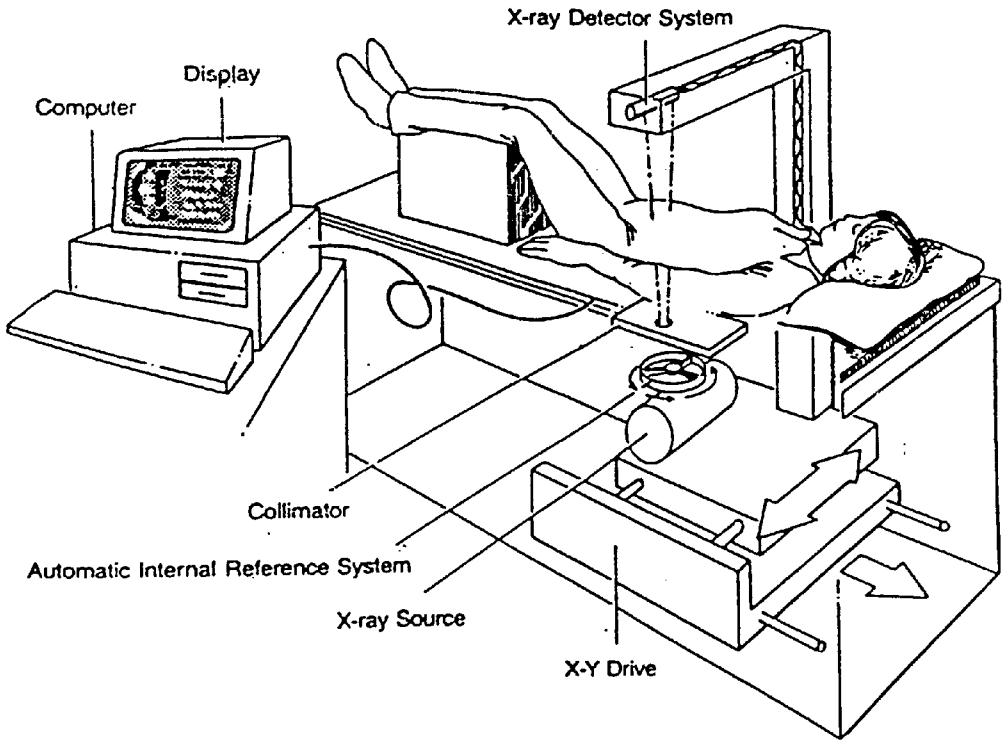


Figure3.4 Schematic diagram of the Hologic QDR pencil beam scanning densitometer (Verlaan and Piper, 1989).

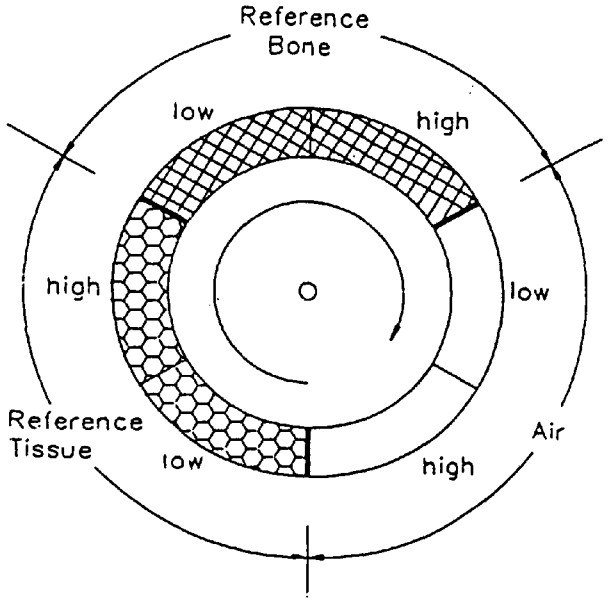


Figure 3.5 The Hologic rotating calibration wheel containing two segments each of bone for internal reference measurement, simulated soft tissue segments for determination of k, and blank areas for direct measurement. One segment corresponds to high-energy pulses and the other to low-energy pulses (Verlaan and Piper, 1989).

The ***Hologic QDR 4500*** uses a C-arm configuration with a source which generates a narrow, collimated, fan shaped beam of X-rays alternating between 100kVp and 140kVp. The detector is also crystal. Calibration is by means of a rotating drum with alternating segments of bone, soft tissue and air equivalents.

The algorithm (Equation 5) used to determine bone mineral content is as follows:

$$Q = L - kH \tag{5}$$

where H = logarithm of tissue attenuation at high energy (140kVp)

and L = logarithm of tissue attenuation at low energy (100kVp)

and k = constant, dependant on the tissue attenuation characteristics of the beam. k is continuously measured using the tissue equivalent segment of the filter drum (Equation 5 from Hologic specifications).

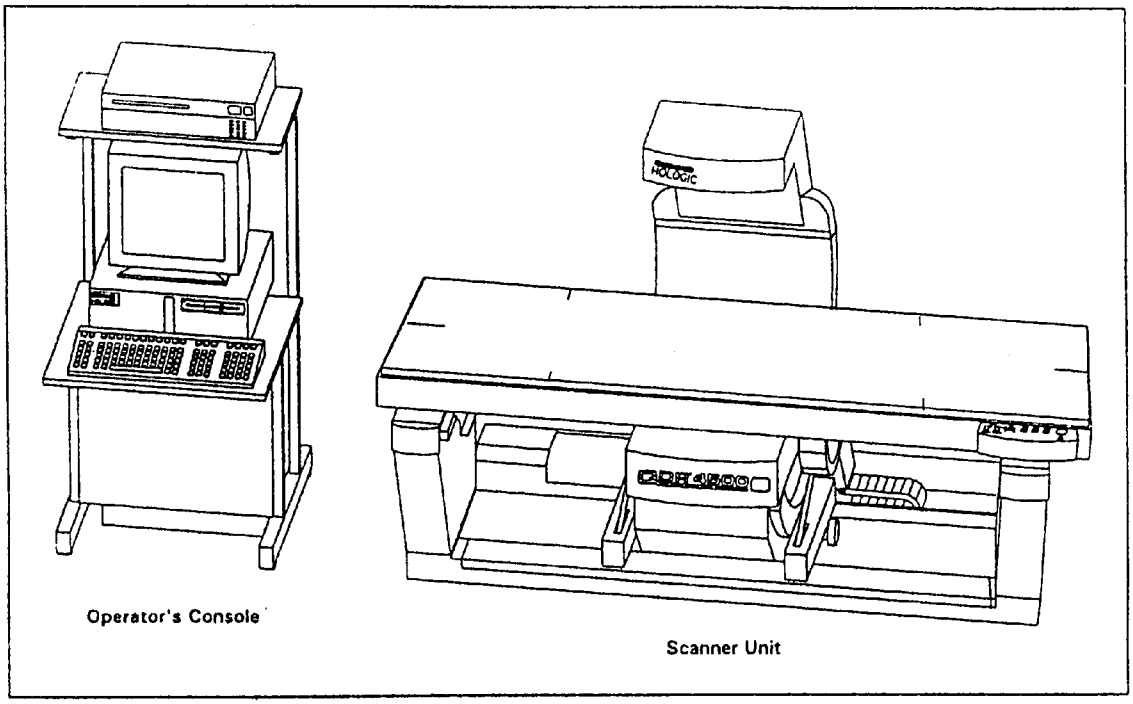


Figure 3.6 Hologic QDR 4500 (information courtesy of Hologic,1995).

Lunar DPX system uses a stable X-ray tube with constant potential, k-edge filtering and a photon counting detector. K-edge filters act on the x-ray spectrum to produce two distinct energy peaks. Using a filter of cerium (350mg/cm^2) produces beam energies of 40 and 70 keV (*figs. 3.7 & 3.8*). Using a samarian filter with potential of 90kVp produces beam energies of 45 and 75 keV (Sorensen et al,1988; Collick et al,1987).

Fig. 3.7 The 80KV Spectrum before filtration (Sorensen et al, 1988).

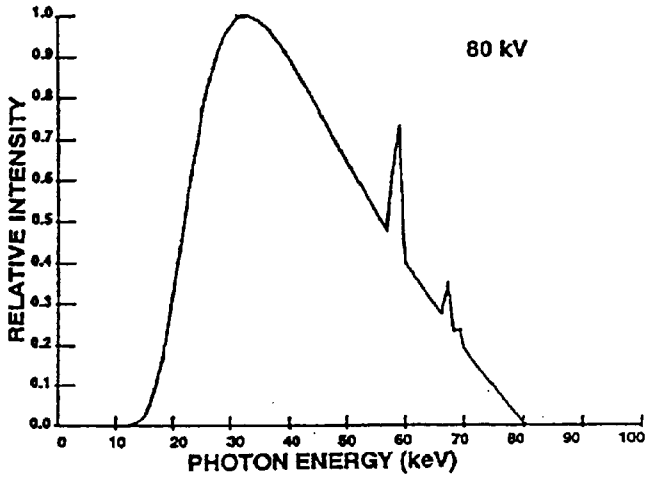
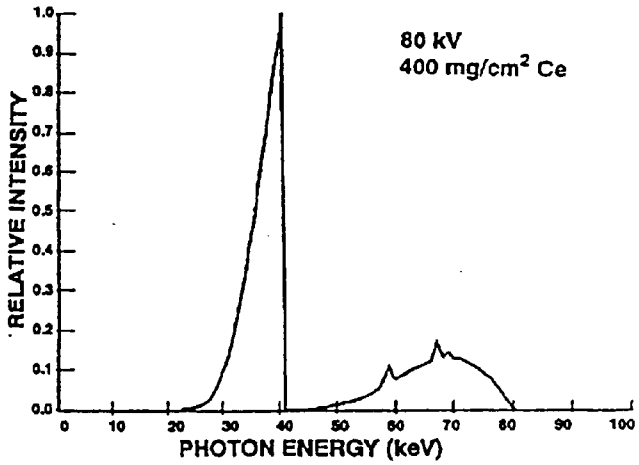


Fig.3.8 The 80 KV spectrum filtered by 350mg/cm^2 of cerium (Sorensen et al, 1988).



Beam hardening and scattering effects are corrected for by the software. The beam exposes each pixel to both energies simultaneously and each photon is detected by a NaI detector/scintillator.

Norland XR-26 Mark II uses a dual detector system with a thin (0.3mm) NaI crystal to filter and detect low energy photons whilst a thick (7mm) NaI crystal detects the remaining higher energy photons. The advantage of this system is in the elimination of the "dead-time factor" at high count rates, where two photons arrive at the detector simultaneously. Norland use samarium filtration to vary the intensity of the incident energy beam. This allows optimum precision at optimum dose for a wider range of body size than the other machines (particularly children and obese patients) (*figs. 3.9 & 3.10).*

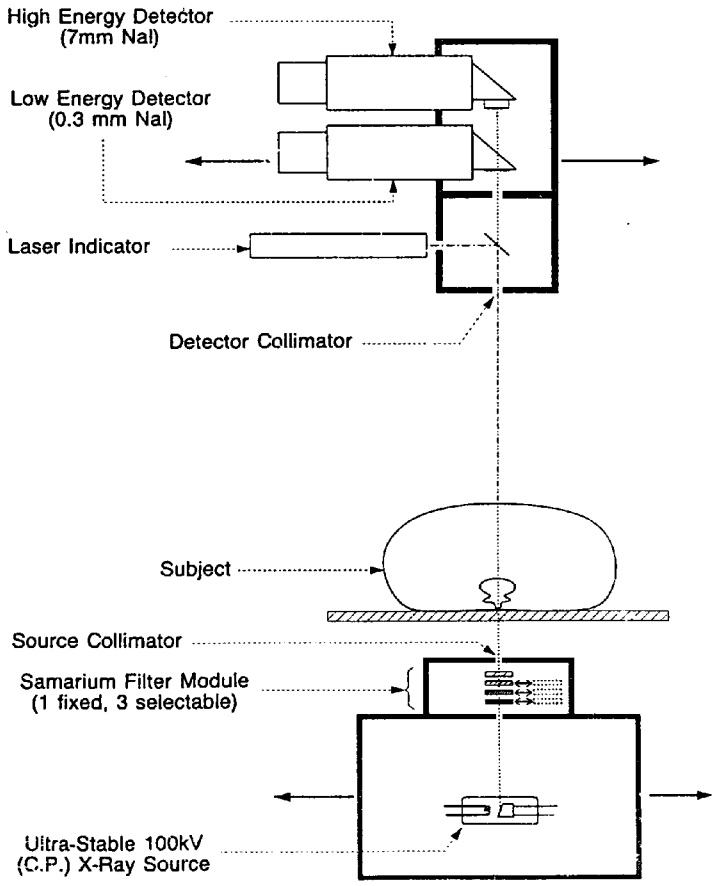


Figure 3.9 Schematic drawing of Norland XR 26

(from Manufacturer's specification).

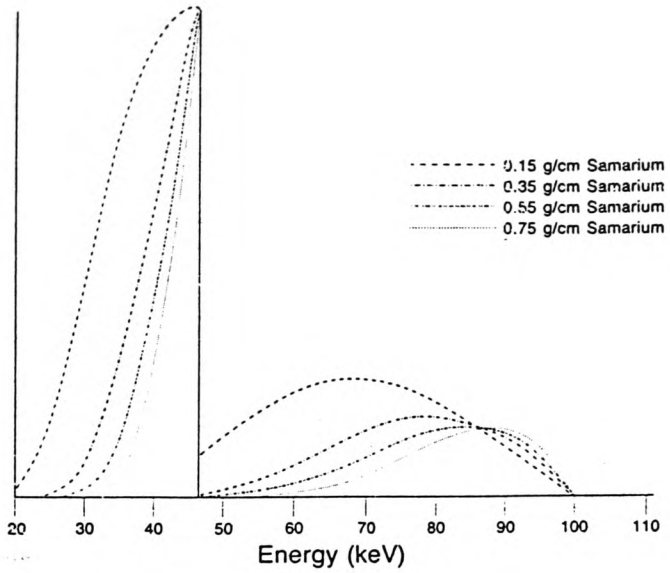


Figure 3.10 Samarium filtered X-ray spectra showing good separation of the two energy peaks (courtesy of Norland).

Sofa also make a DPX system but as these are used in fewer centres they are not discussed here. Comparisons between the DEXA systems have been made by a number of investigators. Differences occur in each case, even when the same subject is scanned on the separate machines. This highlights a major factor in clinical densitometry, where comparison of data between centres using different DEXA systems cannot easily be made (Akai et al, 1990).

Sensitivity, Accuracy and Precision

The performance characteristics of bone mineral densitometers are limited by diagnostic sensitivity, accuracy and precision.

Diagnostic sensitivity

This refers to the ability of the measurement to separate an 'abnormal' patient or population from a normal one and to measure age and disease related bone loss.

Accuracy

This reflects the reliability of the system to produce a true value of bone mineral content. It is generally expressed as the standard error of the estimate of the linear regression of measured bone mineral density versus true calcium content. Accuracy error can be acheived in vitro by scanning a bone which is subsequently ashed to ascertain true calcium content.

Precision

This is the ability of the instrument to reproduce the same result with longitudinal measurements of the same patient/object. Short - term precision for a sequence of measurements of bone density is generally expressed in absolute figures as the root mean squared (RMS) averages of standard deviation (SD) or, as a percentage, the average coefficients of variation (CV) versus time. Glüer, 1995 asserted that averages should be root mean squared to avoid underestimation of imprecision. Long - term precision is expressed as the standard error of the estimate (SEE) of bone density with time to exclude variations due to imprecision of the technique, scanner drift,

recalibrations etc.. Precision error in vitro is established by scanning a phantom many times over a long time interval. Short time precision in vivo can be achieved either by scanning a few subjects many times or many subjects at least twice with intermediate repositioning.

Short-term precision studies are often carried out on young normal subjects, however, in practice it is the older patients who are clinically scanned more often and who produce higher precision errors due to lower bone mineral density and indistinct images. Long term studies are further influenced by bone mineral changes due to ageing increasing the precision error.

Precision Studies have been carried out by many investigators producing a variety of results. Some are summarised in Table 2. These results show that precision studies are highly dependant on the age and condition of the subjects used and upon the analysis methods. Those subjects with lower BMD give greater precision error and short term studies tend to produce lower errors. however, there is considerable overlap. The number of subjects used and the number of repeat scans vary considerably between studies, but both short term and long term studies appear to give acceptable results. In addition Glüer (1995) recommends that there should be 2-3 (short-term) or 3-4 (long-term) measurements carried out per subject in a particular group of at least 27 (short-term) or 14 (long-term) individuals to achieve 1% precision. Hassager (1991) says that, ignoring biological variations, theoretically 10 subjects are needed to detect a 1% difference between measurements if there were a 1% precision error, 200 are required if precision error were 5 %. Obviously both figures increase with biological variation.

Table 2. Precision Studies

Source	Site	Precision	Machine	Population	Details of Study
Nijs et al 1991	AP spine	0.9	DPX	Young normals	12 females per group
		0.6	QDR 1000		6 scanned 2 times on
		1.8	DPX	Osteoporotics	DPX within one week
		0.8	QDR 1000		
		3.5	DPX	Osteoporotics	
		1.5	QDR 1000		
Blake et al 1990	Ap spine	1.4	QDR 1000	Normals	2 subjects scanned on 13 different QDR 1000 machines
	Fem Neck	2.1			
Devogelaer 1990	AP Spine	0.9	QDR 1000	Unknown	18subjects
	Fem Neck	1.6			
	Trochant	1.7			
	Ward's	2.9			
Laskey 1991	AP Spine	0.6	DPX	High BMD	24 subjects scanned twice on both machines : Classed as high or low BMD
		0.8	QDR 1000		
		1.8	DPX	Low BMD	
		1.1	QDR 1000		
	Fem Neck	2.5	DPX	High BMD	
		1.4	QDR 1000		
		2.0	DPX	Low BMD	
		1.7	QDR 1000		
Duboeuf 1991	Fem Neck	1.1	QDR 1000	Young normals	5 subjects scanned 2-6 times short to medium term
	Trochant	1.1			
	Ward's	1.9			8 subjects scanned 3 times
	Fem Neck	1.1		Elderly (>65yrs)	short to med term
	Trochant	2.8			
Orwoll 1991	AP Spine	1.1	QDR 1000	Young normals	1 subject scanned 3 times at 5 centres - 9-12 mths
	Fem Neck	1.2			
	Trochant	1.3			
	Ward's	2.4			
Estillo 1991	AP Spine	1.3	QDR 1000	Post-menopausal (50-60y)	41 females 3+ times at 6 month intervals
	Fem Neck	1.6			
	Trochant	1.6			
	Ward's	2.6			
	Ward's	3.9			
Reginster 1991	AP Spine	0.8	QDR 1000	Young normals	1 subject 50 times long term
	Fem Neck	2.3			
	Trochant	1.5			
	Ward's	5.3			

Manufacturers : Hologic Inc.(QDR 1000) ; Lunar(DPX).

Quality Control

Quality control is necessary to monitor precision and stability of DEXA instruments by identifying any machine drift. The manufacturers use phantoms of different bone mineral equivalent, different soft tissue equivalent and different shape.

Hologic's spine phantom is anthropomorphic shaped, single density calcium hydroxyapatite encased in methyl metharylate plastic (*fig.3.11)*. However, although the shape of this phantom allows for edge detection to be checked, the plastic is not equivalent to true soft tissue. This might lead to variations in compensation for soft tissue effects on different machines. The single density of the phantom does not allow for calibration of the extremes of density range (Faulkner and McClung, 1995).

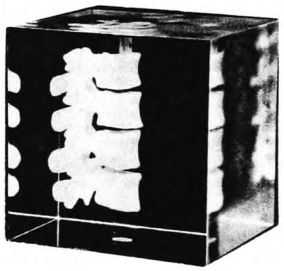


Figure 3.11 Hologic phantom (courtesy of Hologic).

Lunar use an aluminium step phantom simulating four vertebrae of increasing area and density using water as soft tissue equivalent (*fig.3.12).* This represents bone mineral in the presence of fat as a ratio of 1:2 (Mazess et al,1991(c).

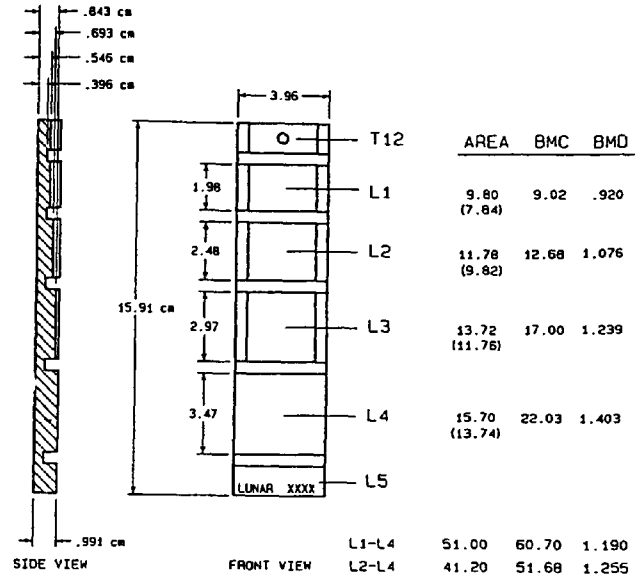


Figure 3.12 Lunar phantom (courtesy of Lunar).

Norland also use an aluminium step phantom, this time in the form of a wedge with a corresponding wedge of acrylic plastic to represent bone mineral and soft tissue. Their method of calibration is to allow for the fact that soft tissue is composed of fat and lean in unknown proportions. Counts are made for 77 combinations of bone / soft tissue (aluminium / acrylic) *(fig.3.13)* and using the 4th degree polynomial describes a smooth curve which approximates the deviations from the ideal in three dimensions so that for each image point, BMD is read off the curve against the high and low energy measurements to correct the machines' inaccuracies.

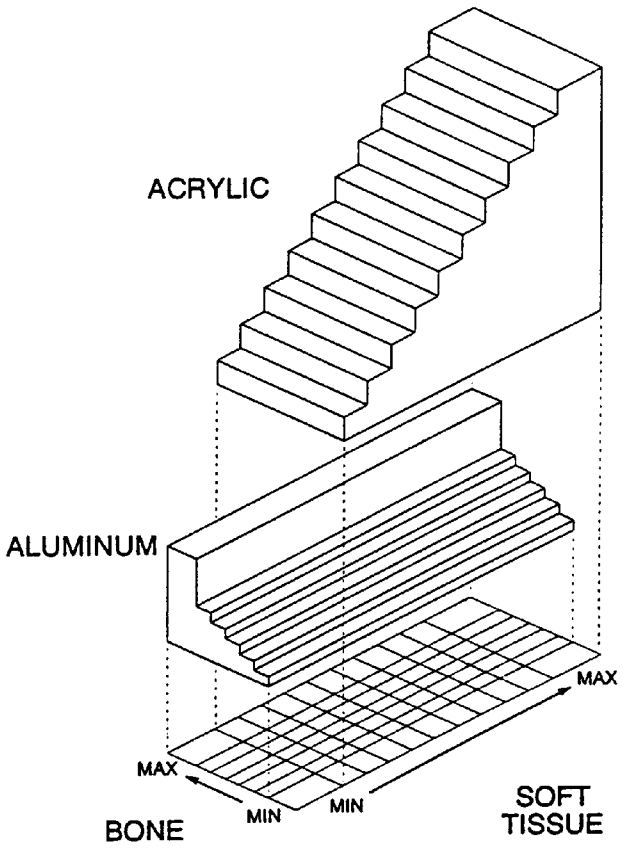


Figure 3.13 Norland phantom (courtesy of Norland).

Comparison of Calibration Techniques..

When the same Al phantom is used to calibrate QDR, XR-26 and DPX scanners the area measurements were highly comparable but BMC and BMD values were 10% higher in the latter (Mazess et al,1991(c)). This is caused by two main factors. The algorithms used for edge detection differ. Hologic and Norland average the soft tissue over the entire image and use this as a baseline above which each reading is considered to be bone, whilst Lunar use the slope of pixels at the bone edge and count all within these edges as bone. This results in a greater area of low density bone being excluded from calculation e.g. the transverse processes. This gives a 6% higher BMD in Lunar measurements (or 2 % in osteoporotic subjects) (Mazess et al 1991(c); Gundry et al, 1990). Thus each manufacturer has used a different course to optimise their results which is why results are not identical.

The medium used to simulate soft tissue differs between the companies. Lunar base their calibration on the ashing of bone samples containing marrow fat. Each g/cm^2 of fat tissue within the bone in theory produces $0.05g/cm^2$ decrease in measured density. Lunar measure their phantom in a medium of water to best simulate this. Hologic and Norland use plastic/acrylics for this medium. When the Lunar aluminium phantom is scanned by QDR 1000 and XR-26 the BMC values produced are 5% lower than their algorithms predict (Mazess et al, 1991(c); Gundry et al, 1990) but closer in value to the Lunar scan BMC value.

There have been many calls for standardisation of calibration phantoms, particularly where multicentre trials are to commence and all machines need to use the same

performance limits. This has led to the development of the European Spine Phantom (ESP) by Kalender et al (1992(b)). This has three vertebrae of different density calcium hydroxyapatite encased in tissue-equivalent plastic. There has been some debate about the effects of edge detection on its ultimate design. Calibration standardisation on each DEXA system is underway.

One of the major difficulties in using bone density measurements in clinical decision making is in the interpretation of results (Eastell and Peel, 1994). BMD measurements by DEXA are in two dimensions and are therefore expressed as g/cm^2. While it is possible to obtain a volumetric expression in g/cm^3, scanning in two planes would be required, a procedure which has not been adopted at the present time. The expression of Bone Mineral Content in grams is dependant on body size so the g/cm^2 expression has gained common usage and termed 'bone density', abbreviated to BMD. A theoretical volumetric bone mineral density (BMAD), derived from dividing BMD by the square root of the area, reduces the dependence of BMD on body weight by 7%. However, precision error is increased to 0.7% (0.5% for BMD) (Mazess et al, 1994).

Chapter four

Chapter 4. The Bone Mineral Density Report.

Physicians want a BMD report to tell them if their patient falls within normal limits or is at risk of fracture from a low BMD or other disease processes if a high BMD. The two most commonly used scan regions are lumbar spine and femoral neck. The reports for individual companies vary on minutiae, but all show the image of the lumbar spine or femoral neck, with accompanying data on region scanned followed by a comparison of that data with a reference range. As we use the Hologic QDR1000 at this hospital I have described these reports in full detail. Reports for Lunar and Norland densitometers are shown in Appendix 1 with Hologic report for comparison.

The Hologic densitometers are all fitted with standard software. Regardless of the model or age of the scanner, a common report format is adopted. This is designed to be an important feature, so that anywhere in the world, a densitometry report can be recognised and read by an experienced operator. The report formats are described as follows:

Lumbar Spine

The DEXA image of the lumbar spine is reproduced in a window, showing the separate regions of interest selected for L1, L2, L3, and L4 *(fig.4.1)*. Over this image are settings which are not required for clinical interpretation. k and d0 are machine settings, only of concern to an engineer checking that the scanner is performing in a standard manner. Below the image, the scan date and time of image analysis are shown followed by two values e.g. (119 x 125). The latter is the window size for the scan displayed.

The make and type of machine, with serial number is also given

e.g. Hologic QDR 1000 (S/N 250).

Finally on the third line below the image, the software used is given

e.g. Lumbar Spine V4.47.

The demographic data is shown in a block starting with a scan serial number and the date and time of the scan. Name, height, weight and age are important data which must be added.

Beneath the demographic data is a one line statement on Coefficient of Variation for the L1-L4 BMD.

The table for values of each vertebra measured, area BMC and BMD are given with the total values on the last line.

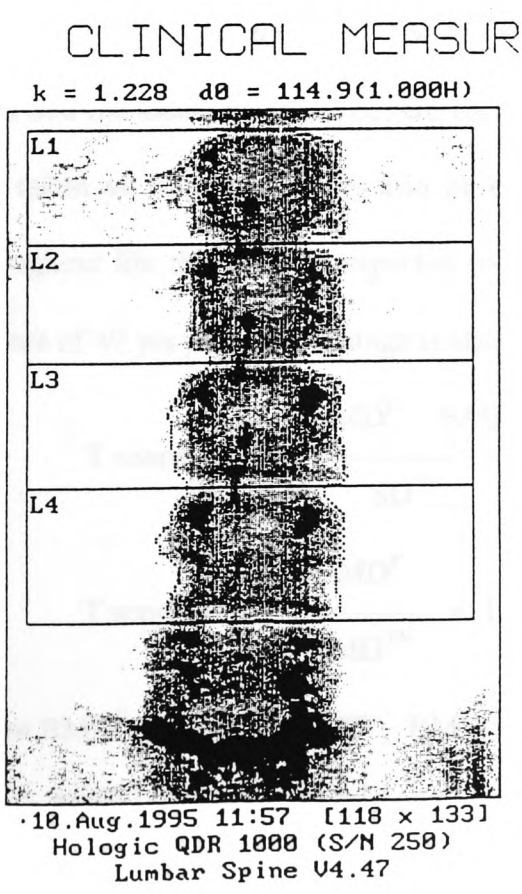


Figure 4.1 Lumbar Spine Report : Image of spine and analysis of regions.

The Report Page, Lumbar Spine

The second page of the lumbar spine report repeats the demographic data, confirming the patient and time of scan *(fig. 4.2)*. A graph plot of normal values for males or females depending on the patient's sex is drawn. The mean values from age 20 yrs to 85 yrs are shown with 2 standard deviations above and below the mean. The patient data is shown as a cross on the graph corresponding to the nearest age set for the patient.

Finally a second table is given which repeats the BMD for each vertebral level and for L1 - L4, with the T- score and Z- score for each value.

The T-score is a young normal reference at age 30 years for male or female as appropriate, expressed as the number of reference population standard deviations between the patient's BMD and the mean BMD of the reference population at the age of peak bone mass, in this case taken as 30 years. It can also be expressed as a negative or positive percentage. Throughout life this value is expected to fall, therefore usually shows a negative value in patients of 40 yrs plus (percentage is also given where 0 = 100%) .

$$\text{T score (SD)} = \frac{BMD^{P} - BMD^{YN}}{SD^{YN}} \qquad (6)$$

$$\text{T score (\%)} = \frac{BMD^{P}}{BMD^{YN}} \times 100 \qquad (7)$$

Where BMD^{P} = patient's BMD , BMD^{YN} = mean BMD for young normals

and SD^{YN} = standard deviation for young normals.

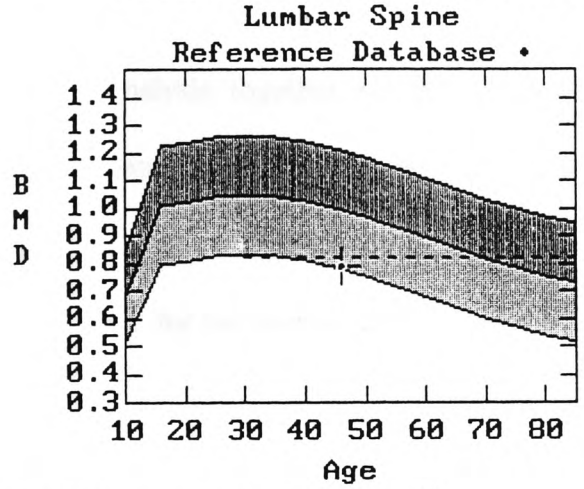
The Z- score relates to the number of standard deviations between the patient's BMD when compared to age and sex matched control data from the reference population. When the Z-score is 0 (100%) the patient result lies on the reference mean line. Below the mean will show as a negative Z-score and less than 100%. Above the mean will produce a positive Z-score and a percentage of more than 100.

$$\text{Z-score (SD)} = \frac{BMD^{P} - BMD^{AM}}{SD^{AM}} \quad (8)$$

$$\text{Z-score (\%)} = \frac{BMD^{P}}{BMD^{AM}} \times 100 \quad (9)$$

Where BMD^{AM} = mean age-matched control BMD and SD^{AM} = standard deviation for age-matched controls.

CLINICAL MEASUREMENT - RNHRD BATH



A05239008 Wed 23.May.1990 11:37
Name: G.C
Comment:
I.D.: Sex: F
S.S.#: - - Ethnic: W
ZIPCode: Height: 155.00 cm
Scan Code: RMP Weight: 46.20 kg
BirthDate: 01.Apr.44 Age: 46
Physician: DAVIES

BMD(L1-L4) = 0.787 g/cm^2

Region	BMD	T(30.0)		Z	
L1	0.650	-2.50	70%	-2.06	74%
L2	0.759	-2.45	74%	-1.96	78%
L3	0.815	-2.45	75%	-1.93	79%
L4	0.879	-2.15	79%	-1.62	83%
L1-L4	0.787	-2.37	75%	-1.86	79%

♦ Age and sex matched
T = peak bone mass
Z = age matched TK 04 Nov 91

HOLOGIC

Figure 4.2 Lumbar Spine Report : Demographic Data

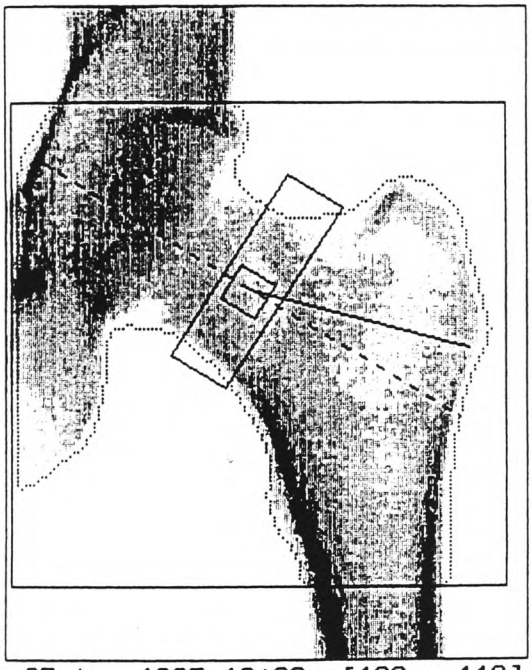
Femoral Neck

Three blocks of data are presented on the first page report, as with the Lumbar Spine. The Image of the hip with analysis regions are displayed. Above the image the machine setting characteristics for k and d0 are repeated. Beneath the image the date and time of image analysis, together with the software version used is displayed. The scanner type and serial number are also shown i.e. Hologic 1000 serial number 250. The second panel gives the standard demographic details of the patient which will be exactly the same as that recorded for the lumbar spine. The date and time of the scan is displayed at this location.

Engineering reference numbers, calibration factor, CF, are also quoted above the third block which relates to the Region, Area, Bone Mineral Content, and Bone Mineral Density in g/cm^2 .The table lists the separate regions which are analysed by the standard analysis programme. These are femoral neck (neck), Trochanter (troch), Inter trochanteral (inter), the whole region (Total) and finally, Ward's triangle (Ward's) which is defined as the weakest part of the femoral neck, a natural triangle created by the collagenous striations.

CLINICAL MEASUREMENT - RNHRD BATH

k = 1.219 d0 = 103.5(1.000H)



·07.Aug.1995 10:33 [120 x 119]
Hologic QDR 1000 (S/N 250)
Left Hip V4.47

A08079503 Mon 07.Aug.1995 10:11
Name: B.J
Comment:
I.D.: Sex: M
S.S.#: - - Ethnic: W
ZIPCode: Height: 176.70 cm
Scan Code: JEH Weight: 76.60 kg
BirthDate: 04.Jul.39 Age: 56
Physician: DR DAVIES

C.F.	1.005	1.033	1.000

Region	Area (cm^2)	BMC (grams)	BMD (gms/cm^2)
Neck	6.58	4.78	0.727
Troch	13.96	9.64	0.691
Inter	28.20	30.69	1.088
TOTAL	48.74	45.12	0.926
Ward's	1.00	0.60	0.597

Midline (116,144)-(216, 82)
Neck -53 x 16 at [29, 7]
Troch 17 x 53 at [0, 0]
Ward's -11 x 11 at [5, 5]

HOLOGIC

Figure 4.3 Femoral Neck Report : Image of hip and analysis of region.

Report Page Femoral Neck

The report page for the femoral neck is as laid out for the lumbar spine *(fig. 4.4)*. The demographic panel is recorded, and the reference graph, usually with the femoral neck result plotted against the age (sex matched) controls. This is headed Reference database, and will specify the hip scanned, left or right.

The table of regions is also given with BMD value repeated, the corresponding T score (this time at age 20 years) and Z scores. An optional panel which may be suppressed if not required provides a Physician Comment. These are remarks about the quality of the scan and the significance of the scores.

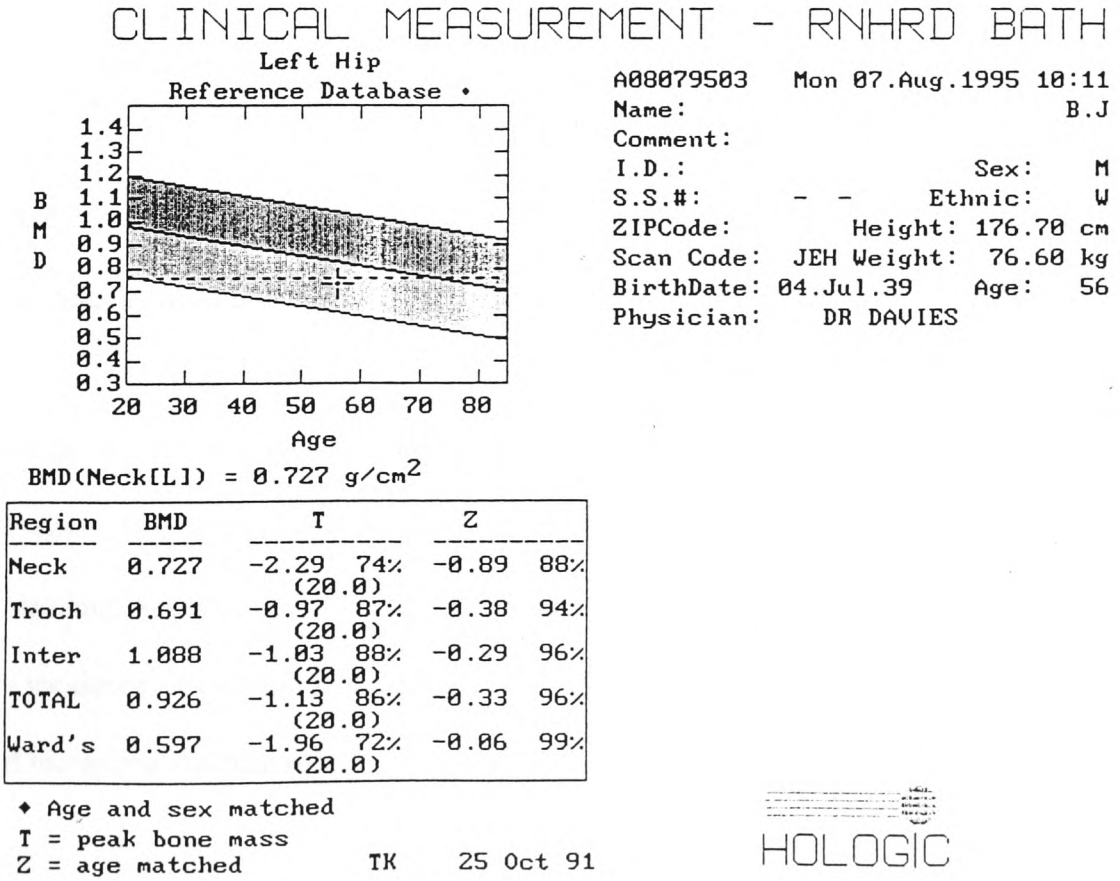


Figure 4.4 Femoral Neck Report : Demographic Data.

Problems of Interpretation

The scan reports are complex, and designed to display many parameters to different grades of technical and clinical staff. From the previous description it is evident that there are data displayed which are dependant on other data for validity. However, much of the data produced in the Hologic reports can be simplified. Centres using this technique vary in their style of reporting. In some, the two pages of printout are given to the General Practitioner or Physician without explanation. Others supply an accompanying letter. In many cases, a simplified report would suffice, providing that the scanning centre has checked the fine details for anomalies. The clinician who is inexperienced in reading these reports can find the whole array of information quite misleading. The natural tendency is to immediately refer to the graph showing the normals plot. However, for many reasons this may be inaccurate.

Z and T-scores may be a better guide to osteopenia, however, there is dispute as to the best indicator. Eastell and Peel (1994) believe that normal comparisons should be with age-matched controls since, assuming the rate of bone loss from the spine is similar among women, the Z-score will be unchanged between 50 and 60 years, whereas T-score will decrease. This might indicate that HRT is required at age 60 but not at 50, which is misleading. Kanis et al (1994) conversely believes that the use of Z-scores is inaccurate as the incidence of osteoporosis will not rise with age despite decreasing bone mass with age and increasing fracture risk.

The generally accepted guideline is that patients who have a BMD plotted above the mean Z-score, are not osteoporotic. If the plot lies below the mean but less than 1 SD,

there may be cause for repeat scans after a time interval of a year or more. The WHO recommends that a T-score of <-1 be referred to as low bone mass and <-2.5 be considered osteoporosis. Therefore, if the plot lies between 1 and 2 SD below the mean, there may be cause to consider treatment. Below 2 SD is at fracture risk.

If there are spurious effects from osteophytes, crush fractures etc. the single BMD value plotted may be falsely high. It is therefore important that all factors are considered before making a diagnostic decision. A single figure, however easy to read, may not be adequate for the true result. The image, is important to the report although it is not always reproduced in the report, (i.e. page 2 is sometimes used alone).

From this picture it is possible to detect artefacts from metal or calcified deposits. In the spine, deformities are often evident, and problems encountered by the technician in selecting separate vertebral levels may also be visible. If a crush fracture has occurred it is often preferable to exclude that level from the total analysis and graph plot. Lateral scans similarly may show the presence of clinical problems such as calcified aorta. This may not affect the lateral spine analysis, but may well elevate the posterior-anterior results. It is not unknown for undiagnosed conditions, even metastases, to appear as a complicating factor arising from bone densitometry .

Chapter five

Chapter 5. Normal Reference Data

Introduction

The ability to measure bone mineral density precisely and accurately has aided the clinician in the diagnosis and management of osteoporosis. For the clinician to identify osteoporosis in an individual, measurements of bone mineral density need to be compared to average values from a sample population of individuals of the same sex, race and age range. The individual result can then be plotted as shown in Chapter 4, against the reference range according to the age and sex of the patient. The range is defined as the mean BMD $\pm$ 2 standard deviations (95% confidence interval).

The reference data used clinically when the densitometers were purchased was that supplied by the manufacturers. Novo supplied reference data from white North American subjects for some body sites and European subjects for other sites as there was insufficient data available at that time from European counterparts. Hologic and Lunar used white American subjects, Norland European subjects. When the Novo Lab DPA 22a was in use at the RNHRD in Bath it was shown that Europeans had a higher BMD on average than their American counterparts (Geusens et al, 1986; Geusens and Dequeker, 1988). This initiated several studies in individual units around the world.

My objective was to check the validity of the manufacturer's reference data by studying a small local population for spine and femoral neck BMD. The most commonly used scanning densitometer is now the DEXA but many hospitals originally used DPA and patients being evaluated over many years have consequently been scanned on both machines. Shortly after a UK reference range had been collected at the RNHRD on the

DPA system, we changed to the Hologic QDR1000. It was important to ascertain if data obtained by both systems was comparable for longitudinal studies and to check if the reference data supplied from American subjects was similar to that of the local population, therefore a smaller cohort of subjects were scanned by both methods to evaluate comparability (Elvins et al, 1990).

Female femoral neck data was not collected from Novo scans because of the lack of reliable reference data at that time and the difficulty in locating the correct site for femoral neck and subsequent scanning time. However, we needed a reference data base for comparison with a small population of ankylosing spondylitis patients and because of the lack of reliable reference data for the male femoral neck, we conducted a small study scanning male femoral neck region in addition to lumbar spine (Will et al, 1989).

Methods and Materials

For each study we used volunteers who were healthy, white Caucasians, drawn from staff members and their families, members of the local population and patients from local G.P.'s lists, selected at random. Each participant was screened to see if they had any medical history including disease known to affect bone mass e.g. hyperthyroidism, removal of both ovaries, OA of the spine or hip, Paget's Disease, or were on any medication likely to effect BMD, e.g. hormone replacement therapy for over three months, thyroxine etc.. If so they were excluded. For the Novo study we used 194 subjects (112 female, 82 males) whose lumbar spine was scanned in region L2 - L4 using the Novo BMC-Lab 22a Dual Photon Densitometer (Novo Diagnostic Systems, DK2880, Bagsvaerd). As there was no acceptable reference data available at this time

for Novo femoral neck these scans were not included in the study. However, 47 males were scanned by Novo in the femoral neck region as part of a separate study and this data is included. All data was grouped for analysis by decade.

For the Hologic reference data 112 subjects (69 female, 43 male) were scanned by the QDR 1000 (Hologic Inc.) in the lumbar spine (L1-L4) and femoral neck regions. 52 subjects (20 male, 32 female) were scanned in the L2 - L4 region on both the Novo Lab 22a and the Hologic QDR1000 for comparison. The regions of analysis were carefully matched and if this comparison was difficult or ambiguous results were excluded.

Results

The raw data resulting from these studies is shown in tables 10 - 17. Tables 3, 4 and 5 show the analysed DPA data whilst tables 6, 7, 8 and 9 show the analysed DEXA data.

Table 3 Normal UK Female BMD Lumbar Spine values measured by Novo Lab 22a, by Decade

Age Group	20-29	30-39	40-49	50-59	60-69	70-79
Mean Age	24.76	36.54	44.58	54.56	65.40	74.25
Number in Group	13	13	13	14	34	25
Mean BMD(gHA/cm^2)	0.94	0.98	0.93	0.86	0.83	0.79
SD of BMD	0.06	0.10	0.07	0.10	0.12	0.12
CV (%)of BMD	6.40	10.60	7.70	11.80	14.10	14.80

Table 4 Normal UK Male BMD Lumbar Spine values measured by Novo Lab 22a, by Decade

Age Group	20-29	30-39	40-49	50-59	60-69	70-79
Mean Age	25.03	34.42	44.57	53.75	66.04	72.96
Number in Group	13	19	10	6	34	25
Mean BMD(gHA/cm^2)	0.97	0.89	0.86	0.87	0.82	0.86
SD of BMD	0.14	0.08	0.13	0.05	0.10	0.16
CV (%)of BMD	14.43	8.99	15.12	5.75	12.20	18.61

Table 5 Normal UK Male BMD Femoral Neck values measured by Novo Lab 22a, by Decade

Age Group	20-29	30-39	40-49	50-59	60-69	70-79
Mean Age	25.42	34.44	44.57	53.18	67.20	-
Number in Group	12	18	10	5	1	-
Mean BMD(gHA/cm^2)	0.93	0.88	0.88	0.84	0.69	-
SD of BMD	0.14	0.10	0.13	0.10	-	-
CV (%)of BMD	15.05	11.36	14.77	11.91	-	-

The correlation between the results obtained from both scanners is shown in *fig.5.1.* The converted Bath DPA data plotted over the Hologic QDR 1000 DEXA reference range are shown in *fig.5.2 and 5.3.* The sample size of the Bath data was less than the supplied data from Hologic, but indicated a less steep fall off in mean BMD in the higher decades. There is a significant difference between the DPA and Hologic individual lumbar spine results ($p<0.01$, Wilcoxon test) but they were highly correlated:

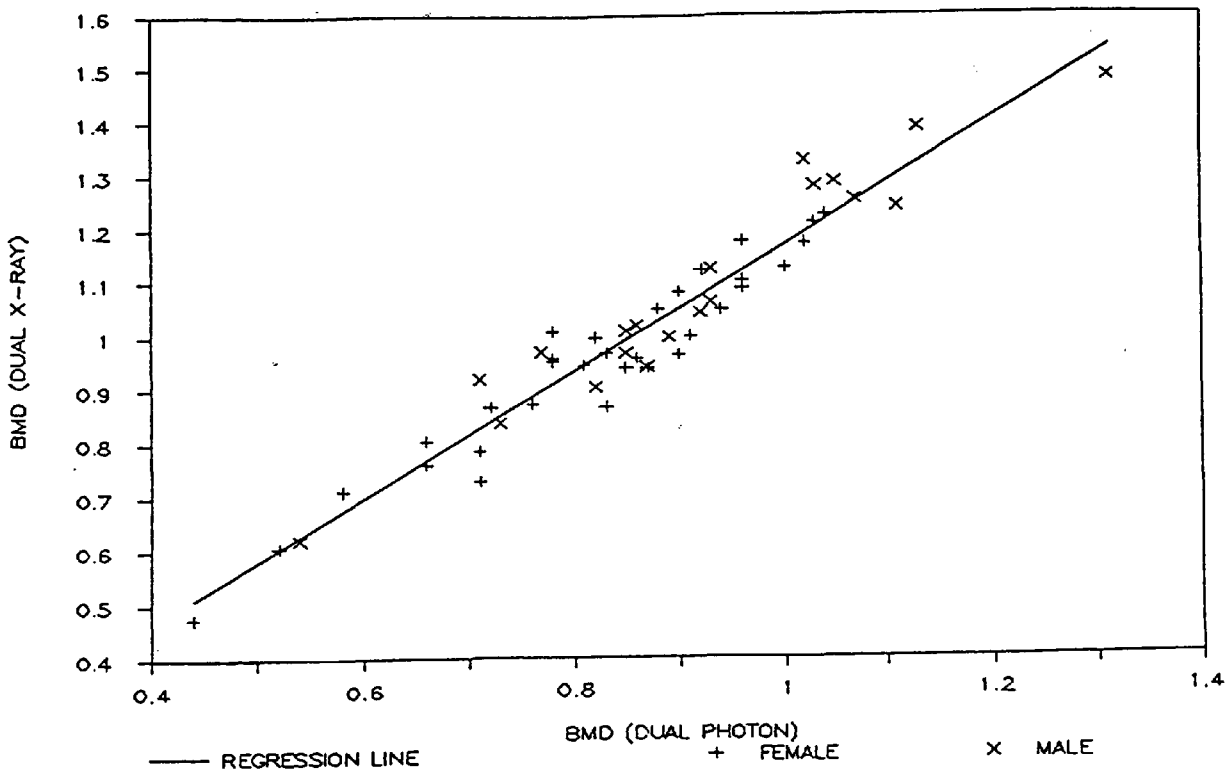
Correlation coefficient, $r = 0.96$, $p=<0.001$

The regression lines for male and female lumbar spine results were found to be statistically identical so the results were pooled to obtain the regression equation:

$$BMD(DEXA) = 1.18 \times BMD(DPA) - 0.0087 \ (gHA/cm^2) \quad (10)$$

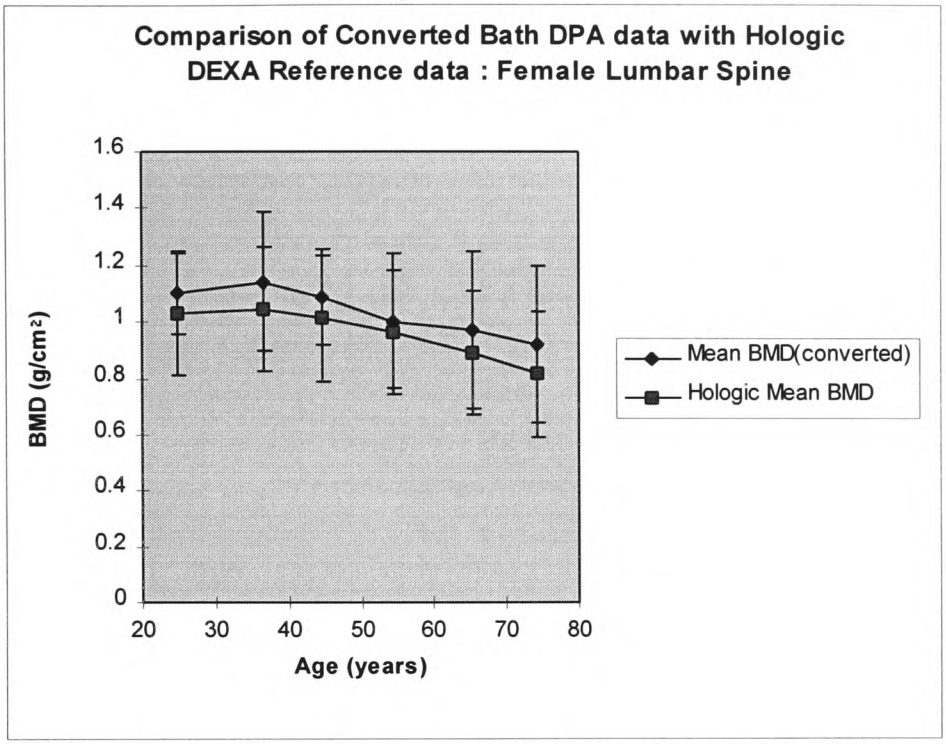
The standard error = 0.055gHA/cm^2, 95% confidence $\pm$ 0.11 gHA/cm^2.

Figure 5.1 Correlation of Bone Mineral Density of lumbar spine (male and female) as measured by DPA and DEXA (gHA/cm^2).



Correlation coefficient = 0.96 p = <0.001

Figure 5.2 Female Lumbar Spine BMD : Converted Bath DPA Data compared to Hologic Control Data



***N.B.* Error bars on *figures 5.2-5.9* and *5.11-5.15* show +/- 2SD**

Figure 5.3 Male Lumbar Spine BMD : Converted Bath DPA Data compared to Hologic Control Data

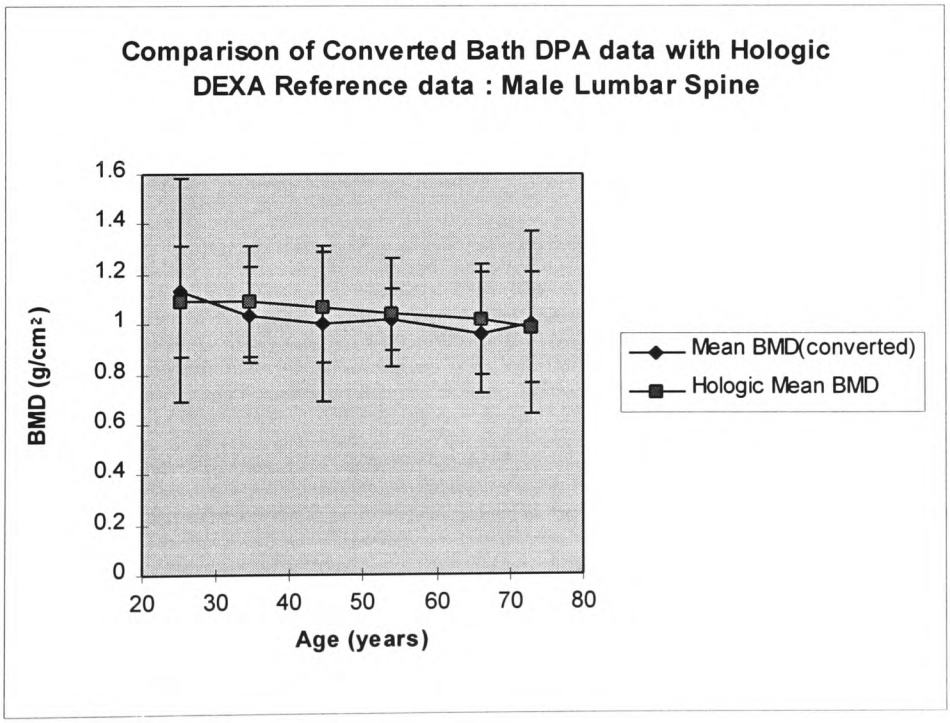
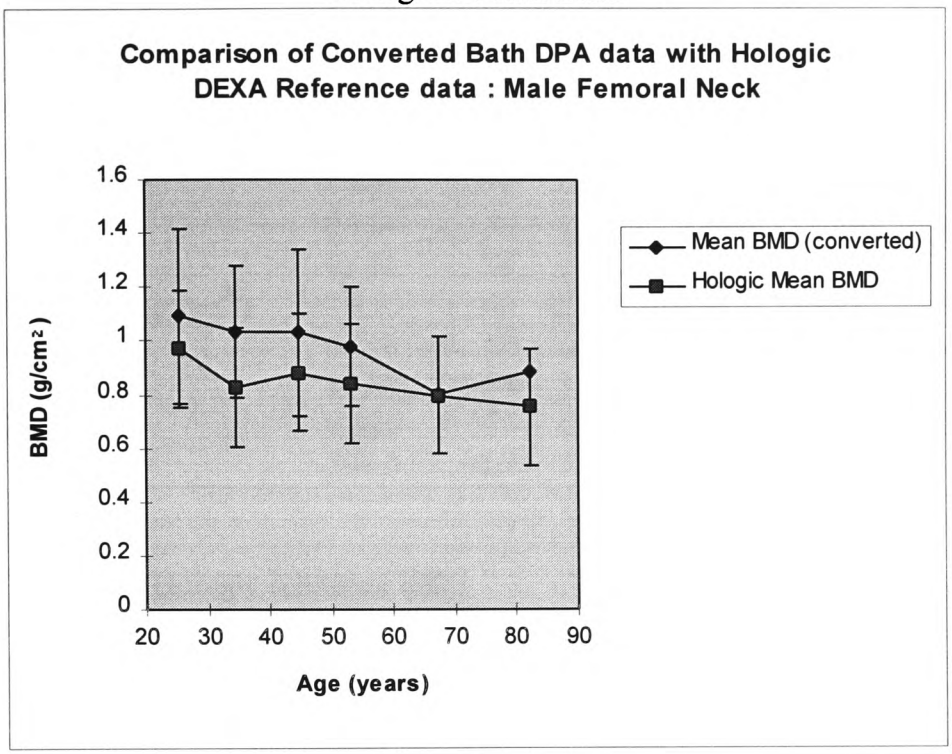


Figure 5.4 Male Femoral Neck BMD : Bath Converted DPA Data compared to Hologic Control Data



Both the converted female lumbar spine and male femoral neck DPA data show much higher values than Hologic reference values. Male lumbar spine DPA shows slightly lower values than the American reference data, with the exception of the +20 and +70 age group, but not statistically so.

Table 6 Normal Bath Female lumbar spine BMD values measured by Hologic 1000, by Decade

Female lumbar spine L1-L4						
Age (years)	20-30	30-40	40-50	50-60	60-70	70-80
Mean Age	24.8	34.0	43.9	54.0	66.0	75.8
No.of subjects	15	7	15	8	17	6
Mean BMD (g\cm^2)	1.094	1.005	1.063	1.008	0.938	0.901
SD	0.133	0.136	0.107	0.176	0.139	0.157
C of V %	12.16	13.53	10.07	17.46	14.82	17.43
Control Mean BMD(g\cm^2)	1.030	1.044	1.012	0.967	0.892	0.815
Control SD	0.110	0.110	0.110	0.110	0.110	0.110
Control C of V%	10.68	10.54	10.87	11.38	12.33	13.50
Z-score(SD)	0.586	-0.355	0.463	0.372	0.418	0.782
Z-score%	106.3	96.3	105.0	104.2	105.2	110.6

("Control" refers to Hologic reference data)

Figure 5.5 Female Lumbar Spine BMD : Bath DEXA Data compared to Hologic Control Data

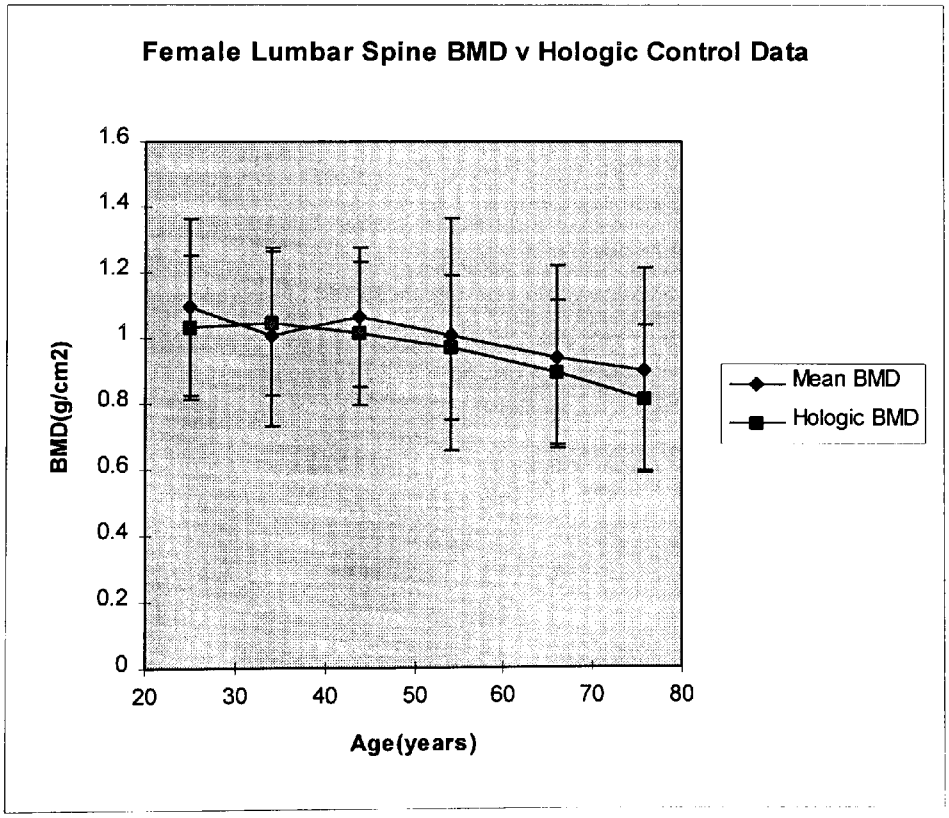


Table 7 Normal Bath Female Hip BMD values measured by Hologic 1000, by Decade.

Age (years)	20-30	30-40	40-50	50-60	60-70	70-80
Mean Age	24.8	34	43.9	54.3	66	75.8
No.of subjects	15	7	15	7	18	6
Femoral Neck						
Mean BMD(g\cm^2)	0.885	0.816	0.788	0.792	0.702	0.723
SD	0.108	0.128	0.085	0.148	0.099	0.121
C of V %	12.20	15.69	10.79	18.69	14.10	16.74
Control Mean BMD(g\cm^2)	0.895	0.884	0.838	0.782	0.717	0.652
Control SD	0.100	0.100	0.100	0.100	0.100	0.100
Control C of V%	11.17	11.31	11.93	12.79	13.95	15.34
Z-score(SD)	-0.095	-0.675	-0.500	0.105	-0.145	0.715
Z-score%	109.8	92.4	94.0	101.3	98.0	111.0
Trochanter						
Mean BMD(g\cm^2)	0.782	0.665	0.707	0.726	0.647	0.657
SD	0.096	0.076	0.087	0.140	0.113	0.111
C of V %	12.28	11.43	12.31	19.28	17.47	16.89
Control Mean BMD(g\cm^2)	0.713	0.720	0.702	0.666	0.617	0.565
Control SD	0.090	0.090	0.090	0.090	0.090	0.090
Control C of V%	12.62	12.50	12.82	13.51	14.59	15.93
Z-score(SD)	0.770	-0.610	0.055	0.672	0.330	1.030
Z-score%	109.8	92.4	100.7	109.0	104.9	116.4
Intertrochanter						
Mean BMD(g\cm^2)	1.169	1.050	1.082	1.030	0.960	0.975
SD	0.144	0.164	0.127	0.187	0.152	0.193
C of V %	12.32	15.62	11.74	18.16	15.83	19.79
Control Mean BMD(g\cm^2)	1.140	1.145	1.118	1.060	0.988	0.898
Control SD	0.140	0.140	0.140	0.140	0.140	0.140
Control C of V%	12.28	12.23	12.52	13.21	14.17	15.59
Z-score(SD)	0.211	-0.679	-0.253	-0.214	-0.200	0.550
Z-score%	102.6	91.7	96.8	97.2	97.2	108.6
Ward's Triangle						
Mean BMD(g\cm^2)	0.844	0.711	0.655	0.659	0.507	0.516
SD	0.141	0.119	0.110	0.152	0.106	0.171
C of V %	16.71	16.74	16.79	23.07	20.91	33.14
Control Mean BMD(g\cm^2)	0.788	0.742	0.674	0.635	0.512	0.434
Control SD	0.110	0.110	0.110	0.110	0.110	0.110
Control C of V%	13.96	14.82	16.32	17.32	21.48	25.35
Z-score(SD)	0.514	-0.277	-0.173	0.218	-0.041	2.830
Z-score%	107.2	95.9	97.2	103.8	99.1	118.9

Figure 5.6 Female Femoral Neck BMD : Bath DEXA Data compared to Hologic Control Data

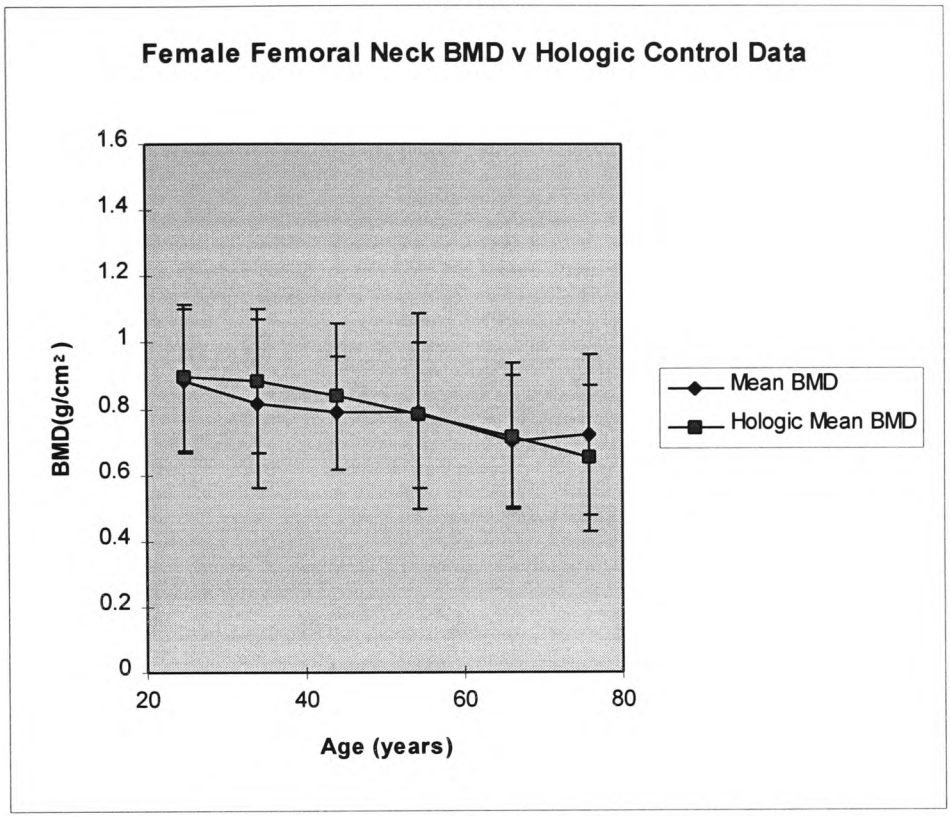


Figure 5.7 Female Trochanter BMD:Bath DEXA Data compared to Hologic Control Data

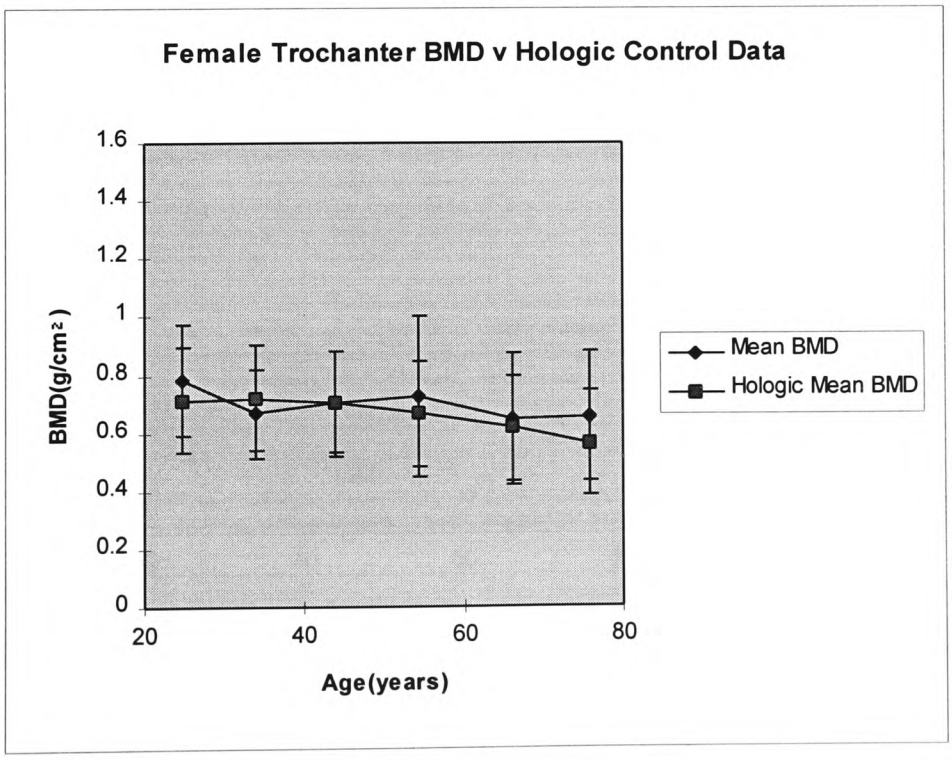


Figure 5.8 Female Intertrochanter BMD:Bath DEXA Data compared to Hologic Control Data

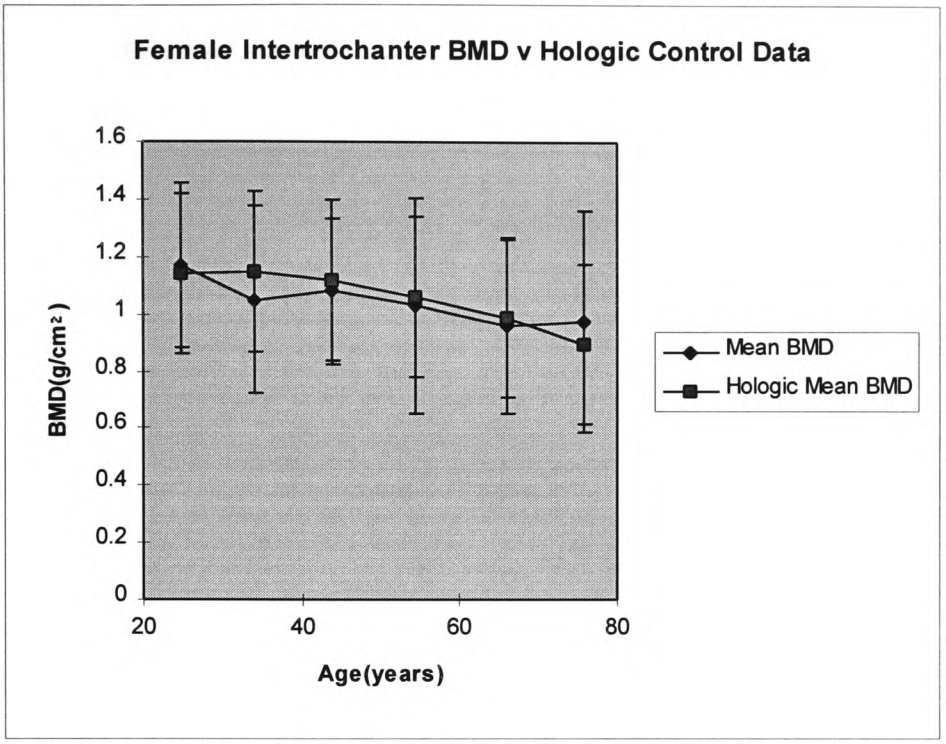


Figure 5.9 Female Ward's Triangle BMD:Bath DEXA Data compared to Hologic Control Data

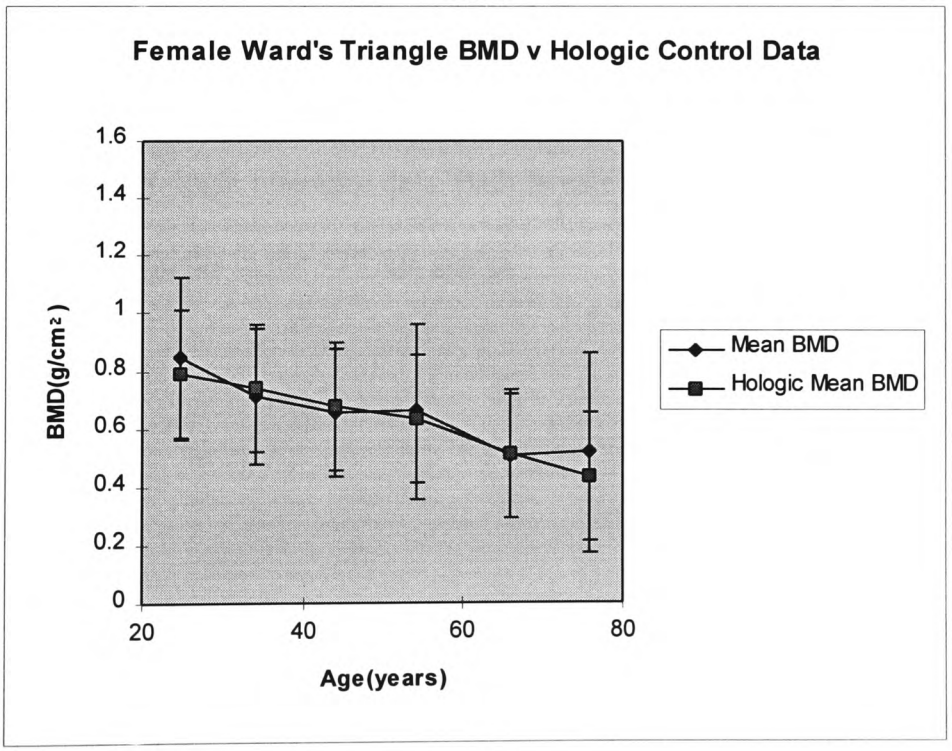
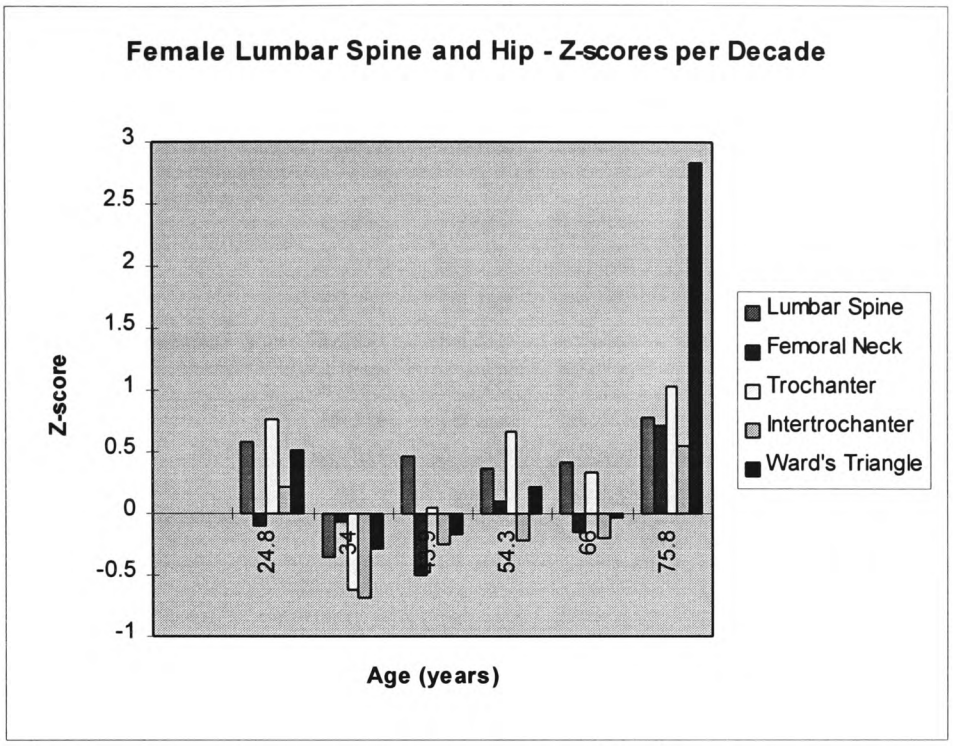


Figure 5.10 Female Lumbar Spine and Hip : Z-scores (SD) per Decade



Bath female lumbar spine BMD values were all significantly higher than the Hologic reference data with the exception of the +30 age group. The fall off in the +70 age group was less steep than Hologic reference data. Bath female hip BMD values showed a less steep fall off in all regions in the +70 age group.

Table 8 Normal Bath Male Lumbar Spine BMD values measured by Hologic 1000, by Decade

Male lumbar spine						
Age (years)	20-30	30-40	40-50	50-60	60-70	70-80
Mean Age	26.8	34.8	44.8	55.3	65.3	71.5
No.of subjects	5	12	7	7	8	4
Mean BMD (g\cm^2)	1.086	1.025	0.996	1.048	1.000	1.138
SD	0.239	0.123	0.199	0.147	0.117	0.181
C of V %	22.01	12.00	19.98	14.03	11.70	15.91
Control Mean BMD(g\cm^2)	1.091	1.091	1.066	1.045	1.016	0.986
Control SD	0.110	0.110	0.110	0.110	0.110	0.110
Control C of V%	10.08	10.08	10.32	10.53	10.83	11.16
Z-score(SD)	-0.045	-0.600	-0.636	0.027	-0.145	1.380
Z-score%	99.5	94.0	93.4	100.3	98.4	115.5

Figure 5.11 Male Lumbar Spine BMD : Bath DEXA Data compared to Hologic Control Data

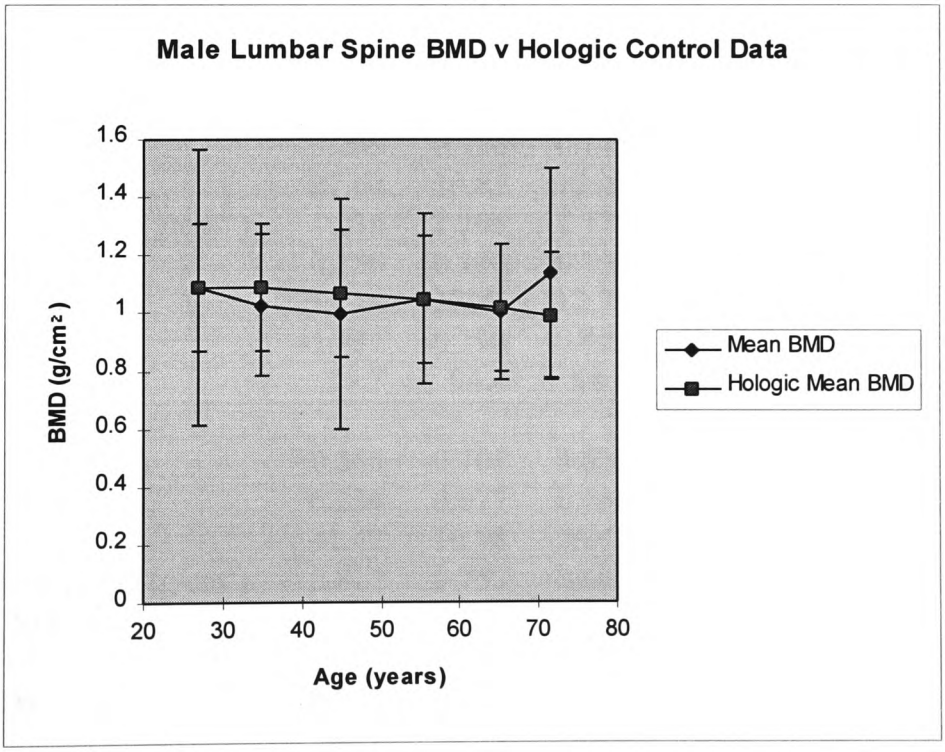


Table 9 Normal Bath Male Hip BMD values measured by Hologic 1000, by Decade.

Age(years)	20-30	30-40	40-50	50-60	60-70	70-80
Mean Age	27.1	33.7	44.8	56.1	65.3	71.5
No.of subjects	4	8	7	6	8	4
Femoral Neck						
Mean BMD (g\cm^2)	0.762	0.872	0.798	0.809	0.763	0.840
SD	0.206	0.100	0.153	0.095	0.142	0.061
C of V %	27.03	11.47	19.17	11.74	18.61	7.26
Control Mean BMD(g\cm^2)	0.969	0.926	0.884	0.841	0.799	0.756
Control SD	0.110	0.110	0.110	0.110	0.110	0.110
Control C of V%	11.35	11.88	12.44	13.08	13.77	14.55
Z-score(SD)	-1.877	-0.486	-0.777	-0.286	-0.323	0.768
Z-score%	78.7	94.2	90.3	96.3	95.6	111.2
Trochanter						
Mean BMD (g\cm^2)	0.631	0.756	0.769	0.777	0.744	0.824
SD	0.214	0.099	0.147	0.125	0.112	0.072
C of V %	33.91	13.10	19.12	16.09	15.05	8.74
Control Mean BMD(g\cm^2)	0.793	0.775	0.757	0.739	0.721	0.703
Control SD	0.110	0.110	0.110	0.110	0.110	0.110
Control C of V%	13.87	14.19	14.53	14.88	15.26	15.65
Z-score(SD)	-1.468	-0.168	0.114	0.350	0.214	1.100
Z-score%	79.6	97.6	101.7	105.2	103.3	117.2
Intertrochanter						
Mean BMD (g\cm^2)	0.960	1.161	1.110	1.144	1.077	1.184
SD	0.265	0.126	0.147	0.162	0.161	0.033
C of V %	27.60	10.85	13.24	14.16	14.95	27.87
Control Mean BMD(g\cm^2)	1.236	1.205	1.174	1.143	1.111	1.080
Control SD	0.150	0.150	0.150	0.150	0.150	0.150
Control C of V%	12.14	12.45	12.78	13.12	13.50	13.89
Z-score(SD)	-1.837	-0.290	-0.423	0.010	0.227	0.693
Z-score%	77.7	96.4	94.6	100.1	96.9	109.6
Ward's Triangle						
Mean BMD (g/cm^2)	0.565	0.701	0.628	0.578	0.505	0.636
SD	0.234	0.077	0.166	0.119	0.129	0.080
C of V %	41.42	10.98	26.43	20.59	23.76	12.58
Control Mean BMD (g/cm^2)	0.817	0.753	0.690	0.627	0.563	0.500
Control SD	0.120	0.120	0.120	0.120	0.120	0.120
Control C of V%	14.69	15.94	17.39	19.14	21.31	24.00
Z-score(SD)	-2.090	-0.430	-0.517	-0.404	-0.483	1.130
Z-score%	69.2	93.1	91.0	92.3	89.7	127.2

Figure 5.12 Male Femoral Neck BMD : Bath DEXA Data compared to Hologic Control Data

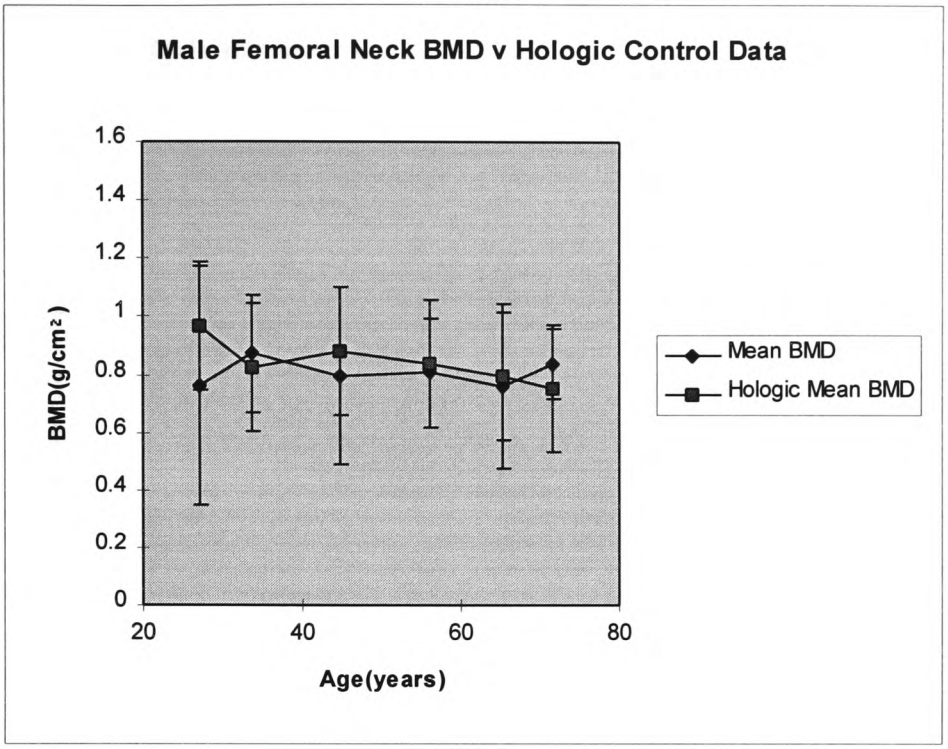


Figure 5.13 Male Trochanter BMD : Bath DEXA Data compared to Hologic Control Data

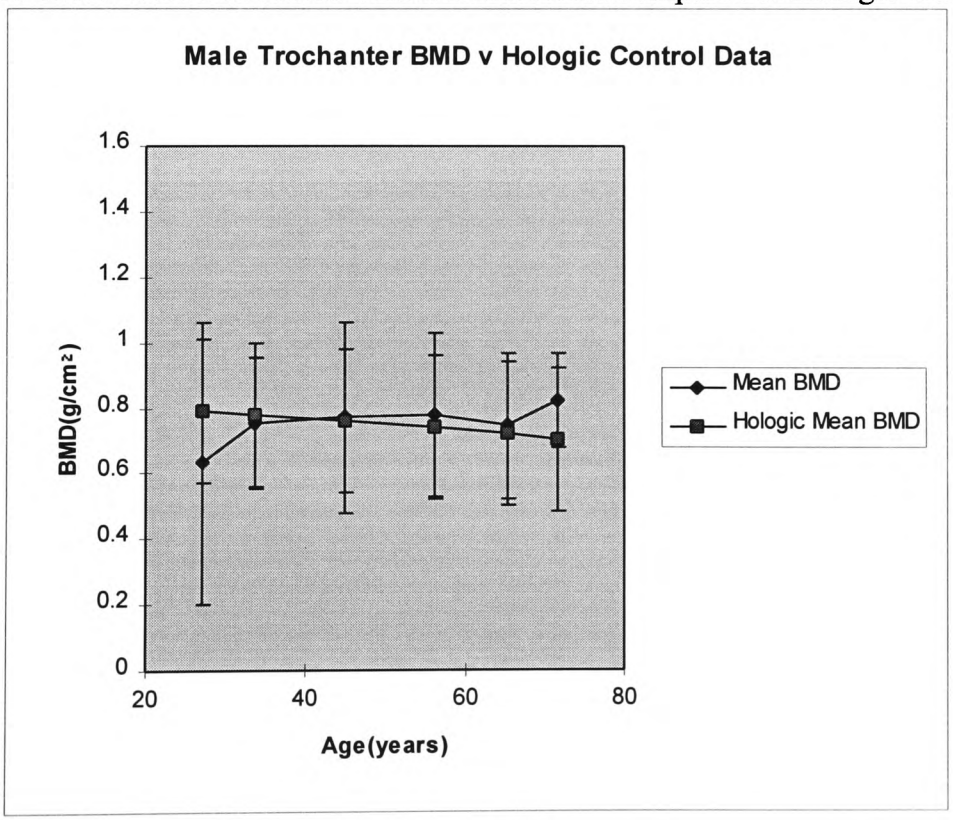


Figure 5.14 Male Intertrochanter BMD : Bath DEXA Data compared to Hologic Control Data

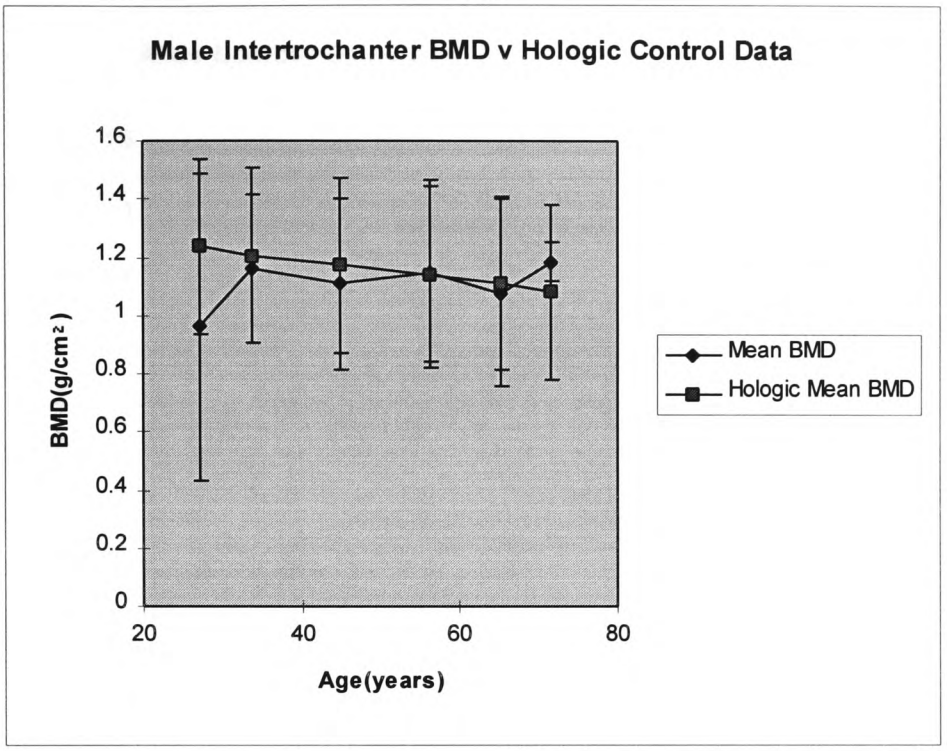


Figure 5.15 Male Ward's Triangle BMD : Bath DEXA Data compared to Hologic Control Data

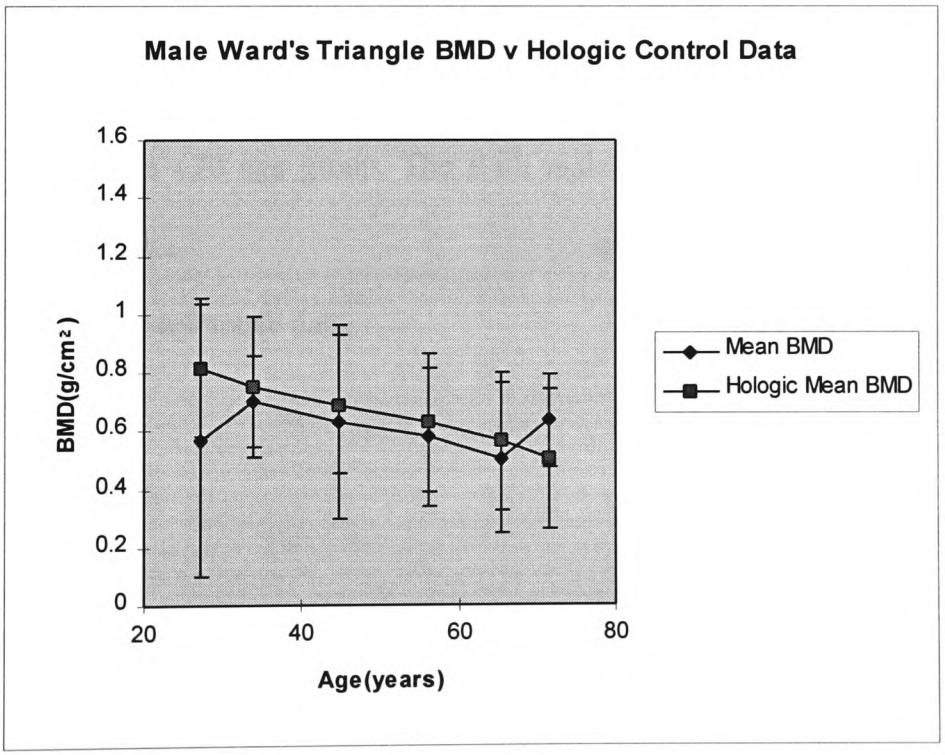
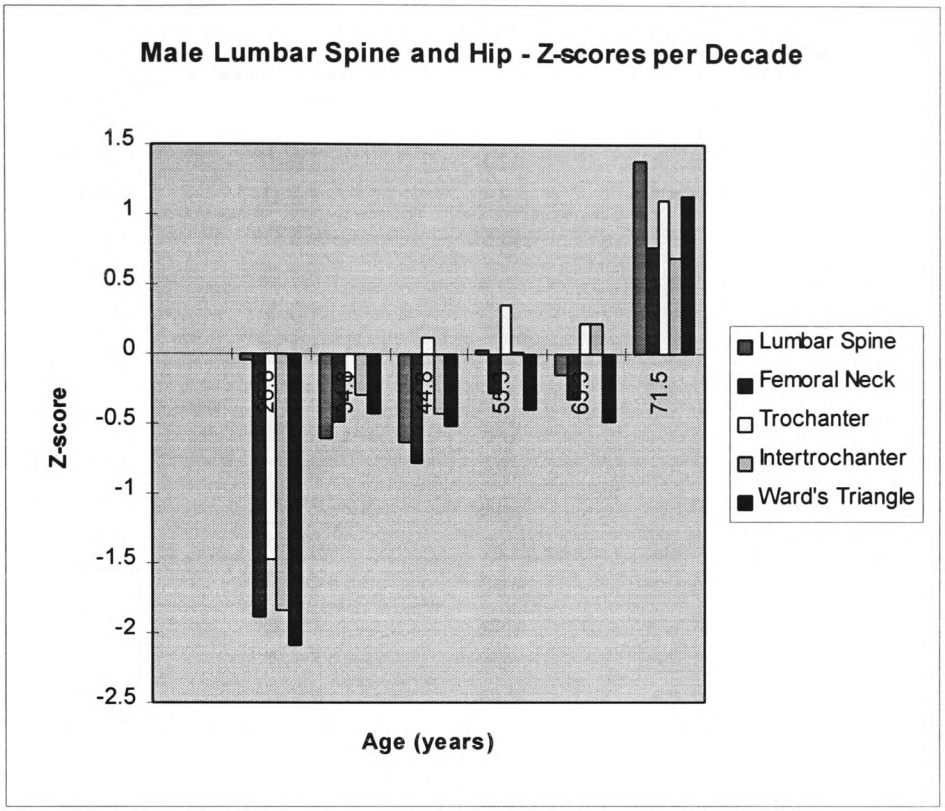


Figure 5.16 Male Lumbar Spine and Hip : Z-scores (SD) per Decade



Bath male lumbar spine data showed significantly higher values compared to Hologic reference data in the +70 age group. The Bath male hip regions showed significantly lower values in the +20 age group and significantly higher values in the +70 age group compared to Hologic reference data.

Table 10 BMD Results (g/cm^2) measured by Novolab 22-a
Female Normals: Lumbar Spine

ID	Age(years)	BMD L2-L4	ID	Age(years)	BMD L2-L4
LE	20.82	0.91	RI	52.28	1.03
ED	20.89	1.01	BA	52.86	0.74
CO	21.07	0.93	MA	55.77	0.76
JO	21.18	0.89	MA	56.42	0.87
GO	23.39	0.85	BU	56.52	0.90
WE	24.34	1.01	LE	57.50	0.83
RO	24.96	0.84	MO	58.39	0.76
WA	25.50	0.99	BE	58.72	0.78
SA	25.82	0.99	FO	59.54	0.73
JO	27.05	0.96	RO	60.31	0.66
HA	29.50	0.97	KE	60.36	0.86
HA	28.98	1.00	MA	60.58	0.81
PA	29.33	0.89	MA	60.63	1.01
CO	31.31	0.88	BO	61.07	0.90
SM	32.70	1.15	RI	62.29	0.97
NI	33.74	0.78	GA	62.96	0.91
PA	34.62	1.06	HI	63.04	0.70
BA	34.68	1.04	SM	64.05	0.70
BE	35.50	1.07	TA	64.46	0.99
RI	36.63	0.91	AB	64.79	0.66
VE	38.67	1.08	HA	64.81	0.73
CO	39.12	0.95	GI	65.05	0.79
PE	39.17	0.94	NI	65.34	0.97
LI	39.44	0.89	JE	65.46	0.70
CA	39.50	0.91	ME	65.79	0.89
PI	39.94	1.02	PE	66.40	0.87
HA	40.71	0.94	EL	66.48	0.84
PH	40.71	0.94	HI	66.56	0.79
FR	41.37	0.89	DA	66.56	0.85
PR	41.94	0.94	ST	66.79	0.96
MI	42.13	1.01	CO	66.85	0.86
TU	43.64	0.90	CU	66.99	0.86
GI	44.48	0.86	PA	67.07	0.77
SM	45.62	0.89	DR	67.08	0.56
DA	45.75	0.78	TH	67.13	0.91
KE	46.95	0.98	GO	67.19	0.96
WA	48.07	1.05	NE	67.20	0.66
GR	48.40	0.91	WE	67.45	0.93
FI	49.80	1.01	SA	67.72	0.87
DA	50.13	0.99	KN	67.95	0.98
SN	50.18	0.79	JO	68.30	0.87
RO	51.65	0.92	SM	69.35	0.65
MI	51.66	0.94	FE	69.55	0.78
SI	52.17	0.97	BO	70.04	0.72

Table 10 BMD Results (g/cm^2) measured by Novolab 22-a
Female Normals:Lumbar Spine (cont.)

ID	Age(years)	BMD L2-L4
DO	70.59	0.76
RO	70.72	0.78
HA	70.82	0.90
UN	70.84	0.87
PE	71.21	0.92
EM	71.79	0.73
SH	72.48	0.72
CR	72.74	0.84
WI	73.22	0.75
SL	73.24	1.03
HU	73.61	0.77
FE	73.65	0.59
WR	73.65	0.67
WA	73.92	0.76
HA	74.58	1.03
PH	75.50	0.98
JE	75.92	0.82
LO	77.11	0.66
RE	77.14	0.66
HA	77.26	0.72
ED	78.33	0.63
SA	79.01	0.81
SU	79.05	0.83
JO	79.95	0.77

Table 11 BMD Results (g/cm^2) measured by Novolab 22-a
Male Normals : Lumbar Spine

ID	Age(years)	BMD L2-L4	ID	Age(years)	BMD L2-L4
BO	20.4	0.86	JA	50.5	0.92
ON	21.1	0.87	FR	52.6	0.93
WI	21.5	0.84	GR	58.6	0.79
RI	23.3	0.82	KE	63.7	0.75
HO	23.6	0.92	NI	64.3	0.65
BE	24.6	1.04	KE	64.5	0.86
ME	26.0	1.31	BE	64.9	0.79
BA	26.2	0.90	ST	65.0	0.96
SY	26.4	1.04	GA	65.0	0.68
ST	27.2	0.87	RO	65.2	0.86
GO	27.4	0.99	SK	65.3	0.74
EL	28.2	1.03	DA	65.5	0.85
EV	29.5	1.11	BA	65.6	0.86
HU	30.2	0.86	HI	65.8	1.06
JA	30.3	0.91	LO	66.3	0.87
BE	30.8	0.79	PR	66.6	0.95
PA	31.5	1.01	CL	66.7	0.75
CS	31.6	0.85	ME	67.1	0.84
PA	31.9	0.81	SY	67.2	0.7
EL	33.7	1.02	DR	67.6	0.82
WI	33.7	0.85	MI	67.7	0.89
MC	33.7	1.04	BR	68.3	0.72
ST	33.9	0.86	RE	68.4	0.87
CA	34.0	0.87	AB	70.3	1.05
CH	35.5	0.96	PE	70.5	0.70
PH	36.1	0.81	FE	71.4	0.97
WI	36.2	0.89	SE	71.8	0.68
LI	36.2	0.84	RE	72.8	0.75
CA	37.9	0.77	BU	72.8	1.14
BR	38.2	0.79	WI	73.1	0.79
WH	38.7	0.97	NA	73.3	0.89
HO	39.8	0.93	WI	73.6	0.85
HA	40.1	0.68	TR	75.3	0.68
OR	42.5	0.78	HU	77.6	0.95
WA	42.6	1.13	BE	80.4	0.74
PE	42.8	0.72	KE	82.2	0.85
LU	43.2	0.84	SM	84.3	0.86
KE	44.7	0.79			
CA	44.9	0.96			
GR	47.1	0.82			
BL	48.1	0.93			
LE	49.7	0.93			

Table 12 BMD Results (g/cm^2) measured by Novolab 22-a
Male Normals : Femoral Neck

ID	Age(years)	BMD FN	ID	Age(years)	BMD FN
ON	21.1	0.80	JA	50.5	0.83
WI	21.5	0.83	KI	50.6	0.98
RI	23.3	0.68	FR	52.6	0.86
HO	23.6	0.84	RI	53.6	0.78
BE	24.6	1.06	GR	58.6	0.73
ME	26.0	1.11	SY	67.2	0.69
BA	26.2	0.95			
SY	26.4	1.05			
ST	27.2	0.85			
GO	27.4	1.03			
EL	28.2	0.88			
EV	29.5	1.11			
HU	30.2	0.75			
JA	30.3	0.79			
BE	30.8	0.91			
PA	31.5	0.98			
CS	31.6	0.87			
PA	31.9	1.00			
MC	33.7	1.04			
WI	33.7	0.75			
EL	33.7	1.01			
ST	33.9	0.74			
CH	35.5	0.90			
PH	36.1	0.85			
WI	36.2	0.91			
LI	36.2	0.86			
CA	37.9	0.86			
BR	38.2	0.74			
WH	38.7	1.05			
HO	39.8	0.85			
HA	40.1	0.63			
OR	42.5	0.75			
WA	42.6	0.90			
PE	42.8	0.97			
LU	43.2	1.09			
KE	44.7	1.00			
CA	44.9	0.85			
GR	47.1	0.85			
BL	48.1	0.95			
LE	49.7	0.82			

Table 13 Comparative BMD Results (g/cm^2) Lumbar Spine L2-L4 : measured by Novolab 22-a vrs those measured by Hologic QDR1000

ID	Sex	Novo BMD	Hologic BMD	ID	Sex	Novo BMD	Hologic BMD
AR	m	1.03	1.281	SM	f	0.90	1.083
BA	f	0.71	0.785	SP	f	0.85	0.941
BA	f	0.81	0.847	SU	f	0.83	0.969
BL	m	0.93	1.127	TH	f	0.92	1.124
BU	f	0.91	1.001	WA	m	1.13	1.389
CA	f	0.90	0.966	WE	f	0.96	1.177
CA	m	0.77	0.971	WI	m	0.89	0.999
CA	f	0.44	0.474	WI	f	0.78	1.009
CO	f	0.78	0.959	WI	m	0.85	0.969
CO	f	0.83	0.868	WI	m	0.73	0.838
CS	m	0.85	1.101				
DA	f	1.00	1.129				
DA	f	0.86	0.959				
EL	m	1.02	1.324				
EV	m	1.11	1.242				
FI	f	1.02	1.175				
FO	f	0.78	0.954				
FR	f	0.52	0.607				
HA	f	0.71	0.730				
HA	f	0.72	0.867				
HA	m	1.07	1.257				
HE	m	1.05	1.289				
HI	f	0.76	0.873				
HO	m	0.93	1.065				
HO	m	0.92	1.045				
HU	m	0.86	1.020				
JO	f	0.96	1.106				
KE	f	0.82	0.997				
KN	f	1.04	1.227				
LO	f	0.66	0.761				
MA	m	0.54	0.621				
ME	m	1.31	1.481				
MI	m	0.71	0.919				
MI	f	0.94	1.051				
NE	f	0.58	0.712				
ON	m	0.87	0.943				
PE	f	0.96	1.090				
RE	f	0.66	0.805				
RI	f	1.03	1.214				
RO	f	0.82	0.905				
SA	f	0.88	1.051				

Table 14 BMD Results (g/cm^2)measured by Hologic QDR 1000
Female Normal : Lumbar Spine

ID	Age(years)	BMD L2-L4	BMD L1-L4
AN	21.6	1.201	1.002
FO	21.7	1.267	1.221
ED	22.3	1.096	1.075
SM	23.4	0.976	0.937
WI	24.2	1.163	1.134
ME	24.8	1.133	1.110
RO	24.8	1.124	1.097
HO	25.0	0.968	0.932
AV	25.1	0.911	0.875
LI	25.3	1.195	1.181
HA	25.6	1.168	1.144
SE	26.1	1.121	1.109
TH	26.6	1.146	1.113
MI	27.4	1.347	1.423
JO	28.2	1.065	1.052
PA	30.3	1.112	1.090
WA	31.3	1.208	1.189
CO	33.0	0.860	0.834
NI	34.3	0.861	0.840
KN	34.4	1.082	1.064
ED	37.0	1.110	1.079
WI	38.0	0.974	0.938
MO	40.6	1.015	0.985
PI	40.7	1.154	1.129
PE	41.1	1.095	1.063
VE	41.2	1.189	1.148
JA	41.9	1.013	0.991
FR	42.8	1.118	1.083
RI	42.9	0.975	0.947
FI	43.5	1.068	1.020
MI	43.5	1.320	1.297
HU	44.8	0.905	0.882
LY	45.8	0.965	0.934
DA	46.2	1.154	1.126
BE	46.5	1.143	1.100
SM	47.5	1.088	1.059
WA	49.3	1.219	1.180
WI	51.1	1.127	1.074
MI	51.7	1.051	1.004
FI	51.9	1.181	1.138
RI	52.3	1.208	1.162

Table 14 BMD Results (g/cm^2) measured by Hologic QDR 1000
Female Normals :Lumbar Spine (cont.)

ID	Age(years)	BMD L2-L4	BMD L1-L4
SI	54.2	1.265	1.242
BA	54.9	0.782	0.753
LA	56.1	0.875	0.855
FR	59.6	0.887	0.837
MO	60.7	1.072	1.042
RE	61.1	0.912	0.870
KE	62.4	0.989	0.942
RO	62.4	1.023	0.991
BU	63.4	1.241	1.187
IN	63.4	0.892	0.859
AT	63.7	0.945	0.915
AX	64.1	1.031	0.986
CO	66.7	0.843	0.795
CH	67.5	0.760	0.732
HO	68.3	0.815	0.772
DA	68.6	0.957	0.929
NE	69.1	0.703	0.686
PA	69.1	0.922	0.891
TH	69.1	1.115	1.085
WE	69.5	1.165	1.144
SA	69.6	1.046	1.010
KN	69.9	1.114	1.055
HA	71.0	1.254	1.156
WI	73.2	1.011	0.982
LO	77.1	0.753	0.728
RE	77.1	0.794	0.764
HA	77.3	0.868	0.848
SU	79.0	0.964	0.925

Table 15 BMD Results (g/cm^2) measured by Hologic QDR 1000
Female Normals : Hip

ID	Age (years)	Femoral Neck	Trochanter	Inter-trochanter	Ward's Triangle
AN	21.6	0.824	0.823	1.231	0.765
FO	21.7	0.856	0.828	1.263	0.780
ED	22.3	0.871	0.850	1.170	0.807
SM	23.4	0.678	0.595	1.022	0.581
WI	24.2	0.744	0.760	1.022	0.753
ME	24.8	0.866	0.768	1.065	0.760
RO	24.8	1.021	0.906	1.149	1.072
HO	25.0	0.851	0.739	0.984	0.890
AV	25.1	0.860	0.648	1.074	0.753
LI	25.3	0.897	0.747	1.121	0.913
HA	25.6	0.961	0.746	1.104	0.978
SE	26.1	0.976	0.931	1.388	0.934
TH	26.6	0.933	0.809	1.259	0.853
MI	27.4	1.116	0.897	1.514	1.113
JO	28.2	0.820	0.680	1.165	0.710
PA	30.3	1.004	0.719	1.207	0.861
WA	31.3	0.866	0.735	1.196	0.740
CO	33.0	0.693	0.657	0.920	0.600
NI	34.3	0.642	0.510	0.781	0.577
KN	34.4	0.916	0.682	1.183	0.855
ED	37.0	0.753	0.711	1.091	0.610
WI	38.0	0.839	0.644	0.971	0.733
MO	40.6	0.768	0.584	0.935	0.588
PI	40.7	0.898	0.826	1.396	0.780
PE	41.1	0.764	0.673	1.104	0.609
VE	41.2	0.836	0.811	1.134	0.690
JA	41.9	0.669	0.639	1.009	0.618
FR	42.8	0.809	0.646	1.034	0.749
RI	42.9	0.617	0.666	0.910	0.446
FI	43.5	0.688	0.550	0.968	0.545
MI	43.5	0.890	0.744	1.141	0.905
HU	44.8	0.754	0.711	1.023	0.574
LY	45.8	0.752	0.671	1.056	0.664
DA	46.2	0.866	0.732	1.068	0.692
BE	46.5	0.826	0.734	1.010	0.574
SM	47.5	0.891	0.752	1.242	0.690
WA	49.3	0.786	0.864	1.205	0.704
WI	51.1	0.808	0.714	0.964	0.656
FI	51.9	0.792	0.863	1.156	0.667
RI	52.3	0.825	0.740	1.035	0.734
SI	54.2	1.060	0.933	1.355	0.946
BA	54.9	0.608	0.585	0.763	0.474

Table 15 BMD Results (g/cm^2) measured by Hologic QDR 1000
Female Normals : Hip (cont.)

ID	Age (years)	Femoral Neck	Trochanter	Inter-trochanter	Ward's Triangle
LA	56.1	0.638	0.537	0.913	0.552
FR	59.6	0.810	0.712	1.023	0.584
MO	60.7	0.746	0.635	1.047	0.456
RE	61.1	0.658	0.604	0.917	0.554
KE	62.4	0.649	0.588	0.888	0.458
RO	62.4	0.697	0.595	0.943	0.582
BU	63.4	0.787	0.860	1.114	0.616
IN	63.4	0.667	0.586	0.928	0.559
AT	63.7	0.738	0.801	1.005	0.551
AX	64.1	0.749	0.658	1.005	0.476
CO	66.7	0.582	0.630	0.952	0.384
CH	67.5	0.703	0.605	1.011	0.499
HO	68.3	0.578	0.492	0.698	0.350
DA	68.6	0.641	0.546	0.813	0.400
NE	69.1	0.567	0.414	0.681	0.354
PA	69.1	0.661	0.674	0.843	0.564
TH	69.1	0.816	0.764	1.094	0.619
WE	69.5	0.985	0.802	1.320	0.760
SA	69.6	0.714	0.688	0.940	0.441
KN	69.9	0.706	0.706	1.087	0.498
HA	71.0	0.801	0.644	1.040	0.693
WI	73.2	0.761	0.713	1.136	0.551
LO	77.1	0.538	0.490	0.742	0.333
RE	77.1	0.716	0.717	1.068	0.541
HA	77.3	0.641	0.578	0.721	0.292
SU	79.0	0.879	0.799	1.143	0.685

Table 16 BMD Results (g/cm^2) measured by Hologic QDR 1000
Male Normals : Lumbar Spine

ID	Age(years)	BMD L2-L4	BMD L1-L4
RI	23.3	0.903	0.850
ME	26.0	1.488	1.433
BL	26.3	1.046	1.000
ON	29.1	0.935	0.926
EV	29.5	1.235	1.222
HU	30.2	1.021	0.996
CS	31.6	1.096	1.071
JA	32.1	1.009	0.972
PA	33.6	1.081	1.051
EL	33.7	1.324	1.307
WI	33.7	0.952	0.916
CU	34.5	0.929	0.906
CH	35.5	1.142	1.121
WI	36.2	0.993	0.970
BR	38.2	0.869	0.845
SH	38.4	1.152	1.130
HO	39.8	1.058	1.020
HA	41.9	0.837	0.829
WA	42.6	1.393	1.358
CH	43.3	0.898	0.882
OR	43.5	0.817	0.818
KI	44.7	0.892	0.890
BL	48.0	1.127	1.082
LE	49.8	1.139	1.116
JA	50.5	1.115	1.098
CH	53.6	0.876	0.856
RI	53.6	0.969	0.956
SI	54.2	1.023	1.008
AL	57.9	1.010	0.973
MA	58.5	1.185	1.142
PE	58.5	1.323	1.306
RO	60.5	1.003	0.960
BE	63.2	1.121	1.105
HE	65.0	1.048	1.056
ED	65.3	0.815	0.801
MO	65.4	1.076	1.065
CR	65.7	1.014	1.008
SE	67.5	1.184	1.135
CH	69.5	0.881	0.869
CO	70.2	1.182	1.167
BU	70.5	1.197	1.177
HI	71.0	1.336	1.320
TA	74.1	0.888	0.887

Table 17 BMD Results (g/cm^2) measured by Hologic QDR 1000
Male Normals : Hip

ID	Age (years)	Femoral Neck	Trochanter	Inter-trochanter	Ward's Triangle
RI	23.3	0.689	0.538	0.785	0.476
BL	26.3	0.766	0.630	1.001	0.607
ON	29.1	0.832	0.726	1.093	0.612
EV	29.5	1.157	1.030	1.422	1.016
HU	30.2	0.779	0.686	1.116	0.638
CS	31.6	0.904	0.753	1.228	0.779
JA	32.1	0.823	0.667	1.031	0.692
PA	33.6	1.085	0.852	1.320	0.805
WI	33.7	0.807	0.670	1.012	0.642
CU	34.5	0.790	0.705	1.098	0.588
CH	35.5	0.874	0.770	1.130	0.702
SH	38.4	0.912	0.946	1.350	0.764
HA	41.9	0.576	0.658	0.968	0.390
WA	42.6	0.909	0.942	1.271	0.749
CH	43.3	0.781	0.700	1.032	0.644
OR	43.5	0.737	0.607	1.062	0.582
KI	44.7	0.659	0.698	1.017	0.454
BL	48.0	0.995	0.995	1.363	0.859
LE	49.8	0.927	0.781	1.059	0.719
CH	53.6	0.753	0.688	1.085	0.458
RI	53.6	0.734	0.642	1.015	0.498
SI	54.2	0.892	0.903	1.356	0.670
AL	57.9	0.735	0.662	0.952	0.532
MA	58.5	0.778	0.882	1.137	0.537
PE	58.5	0.962	0.886	1.316	0.772
RO	60.5	0.616	0.697	0.848	0.447
BE	63.2	0.929	0.780	1.202	0.609
HE	65.0	0.722	0.747	1.026	0.456
ED	65.3	0.608	0.532	0.927	0.311
MO	65.4	0.870	0.893	1.248	0.628
CR	65.7	0.783	0.752	1.177	0.585
SE	67.5	0.949	0.861	1.251	0.643
CH	69.5	0.625	0.690	0.939	0.359
CO	70.2	0.909	0.895	1.140	0.726
BU	70.5	0.761	0.737	1.206	0.557
HI	71.0	0.850	0.869	1.211	0.679
TA	74.1	0.839	0.793	1.179	0.581

Discussion

Whilst the results for the Novo/Hologic comparison were highly correlated the standard error was too great to allow direct comparison of results by both scanners on the same patient. Several centres in the UK have undertaken local studies e.g. Haddaway et al, 1992 and Petley et al,1996. Subsequently, a Belgian population study was published, which represented a Northern European group, compared to the US sample (Reginster et al, 1995). A closer agreement was found between the local and European range.

For volunteers scanned on the Hologic 1000 the sample size was small particularly in the male group and thus open to more errors than the large numbers used by the manufacturer's data base. We could not hope to equal this number due to limited availability of scan time. However, the study consistently indicated higher values of BMD both in spine and hip regions in the 70-80 year old age group. This is also the group which tended to have the fewest subjects. Recruitment of this age group is difficult as many subjects fell within the exclusion criteria, whilst others were too ill to attend due to other medical conditions. Those who remained acceptable were the fitter section of the community who, by virtue of that might be expected to have higher values of BMD than their bedridden counterparts.

It is very important to consider what the term "normal" implies. In the older population many people suffer from conditions which will effect BMD measurements e.g. arthritis, crush and wedge fractures, osteophytes on the vertebral body, calcification of the blood vessels, end plate hypertrophy etc. (see chapter 6). These may not be visible without the aid of a lateral view radiograph. If normal volunteers are X-rayed these factors can be

eliminated, but in many studies this has not been done because of the expense involved and the high doses involved to the volunteer. If one is comparing a patient with no such abnormalities against such a control group their result will be erroneously low and treatment might be prescribed which is unnecessary (further discussion in Chapter 6).

After some five years, a further change has been made in Bath, by the installation of a fan-beam C arm Hologic QDR4500. Comparisons have been made between the two Hologic machines with a group of volunteers. A good overall correlation has been found, but individual results may differ by up to 4%. This highlights the problem with this new and developing technique. Ideally, each centre should recruit control subjects to establish a local reference range. However, the number of subjects required to plot an age range from 15 years to 85 years with statistical certainty is large. Few centres have either the time or the funding to carry out such studies. It is also important to distinguish between those subjects who volunteer (self referral) and those who are randomly selected in order to eliminate a bias in the population (Ryan et al,1993).

In practice, the manufacturers are now using very large data bases for constructing these ranges. The results do not, however, seem to be identical, and certainly vary between manufacturer's systems. Simmons et al (1995) surveyed 67 DEXA centres in the UK . They found a marked variation in the normal ranges used, even between centres using the same model of DEXA equipment. In all, 13 different ranges were in use for the spine, and 11 for the hip, combining to form 15 separate ranges. This has a direct affect on the management and diagnostic criteria, which will be used across the country as a whole. An attempt to improve consistency of bone mineral measurements has been

made by the European Community project COMAC BME. The universal phantom (ESP) which has been developed has been measured at a large number of sites, to calculate a possible conversion factor (Kalender, 1992).

Chapter six

Chapter 6. Scanning Errors

Abnormal Lumbar Spine Scans.

Introduction

DEXA was designed to limit intervention by the operator when scan analysis takes place, thus reducing errors involved in personal judgement. However, this is only possible where scans are straightforward with good anatomical definition of the bone edges. This hospital is a Rheumatology centre and the majority of patients scanned here (using Hologic QDR 1000) have conditions affecting the lumbar spine which necessitate intervention to a lesser or greater degree. Krølner et al (1982) showed that patients with radiographically defined spondylosis and calcification of the abdominal aorta had higher BMC levels than controls. Pouilles et al (1988) stated that aortic calcification had no significant influence but only studied a small number of patients. They also showed the small influence of compression fractures and apparently large influence of osteophytes. Ross et al (1988) found that dual photon spine BMC was adversely influenced by aortic calcification, arthritis and other disease processes (Japanese subjects).

Uebelhart et al (1990) studied 15 patients with osteoarthritis of the posterior processes and showed that Z-score values were higher in P-A projection but normal in lateral scans. Dawson Hughes et al (1990) showed that rate of loss of BMD (adjusted for % reference weight, dietary calcium and years since menopause) was lower in women with abnormalities on their spine radiographs than those with normal radiographs, whereas change of BMD at the radius was independent of this. Orwoll et al in 1990 showed that

osteophytic calcification exerted an important influence on spine bone mineral density in men. Reid et al (1991) showed this to be less important in post-menopausal women as did Frohn et al (1991) whose results largely agreed with Pouilles, but found more influence from severe aortic calcification($>0.039/cm^2$).

Ross et al (1987) also found that lateral lumbar spine radiographic abnormalities increased with age. He found that approximately 11% of the subjects studied had calcification of the aorta and 24% had osteophytes, although the severity of osteoarthritis was not defined. Dawson Hughes et al (1989) agreed with the proportion of subjects with calcification of the aorta but found that only 2% of the population studied had osteoarthritic changes.

A recent study by Whitehouse et al (1992) has shown that osteophytes were present in over 50% of the 60+ years of age population studied. The greatest increase of BMD (measured by DEXA) was due to the presence of fractures in the lumbar spine, compared to the results obtained by QCT on the same subject. Osteophytes, disc space narrowing and facet joint disease also significantly affected BMD results but to a lesser extent.

My objective was to study the incidence of abnormalities encountered in the daily investigative scans at the RNHRD and to check the problems associated with the results obtained.

Method and Materials

500 sequential lumbar spine bone densitometry investigations, 435 females and 65 males, were studied to check the problems associated with the BMD results obtained. Each of these patients had a radiograph of the lateral spine. Of these 500, 100 individuals were to be controls for other studies and were considered to be free from clinical problems (Ring et al, 1991).

The densitometer (QDR 1000) was calibrated each day using the manufacturer's phantom according to standard procedure.

Results

6% of these controls produced scans which were difficult to analyse due to varying conditions - table 18.

Table 18	**Controls for BMD lumbar spine n =100**	**(94F, 6M)**
	Extra vertebrae	3
	Crush Fracture L4	1
	Spina Bifida Occulta	1
	Peridiscal Vertebral Studies	1

From the group of 400 clinical cases a variety of problems were identified : 19.25% produced complications in scan analysis (see table 19).

Table 19 Clinical sample for BMD Lumbar Spine n=400 (341F, 59M)

Vertebral Haemangioma	1
Crush fractures	26
Degenerative & Osteophyte changes	27
Ankylosing Spondylitis	5/11
Extra Ribs/Vertebrae	5
Calcification Aorta	3
Kyphosis/Scoliosis	4
Spinal Fusion/Laminectomy	4
Undiagnosed Paget's Disease	1
Gold Therapy	1
Total	**77 (19.25%)**

Five of the eleven subjects with early ankylosing spondylitis scanned had extra skeletal calcifications of the paravertebral ligaments which tends to increase the mean BMD of the lumbar spine.

One patient on long term gold therapy, had increased mineral content of surrounding soft tissue. The resultant scan by DEXA was too indistinct to be of clinical value.

The following examples show a DEXA image and values of BMD and corresponding areas of L1 - L4 for patients with a variety of clinical conditions (*figs. 6.1 - 6.5*).

Figure 6.1 Patient has kyphosis (forward curvature of the spine) and scoliosis (lateral curvature of the spine).

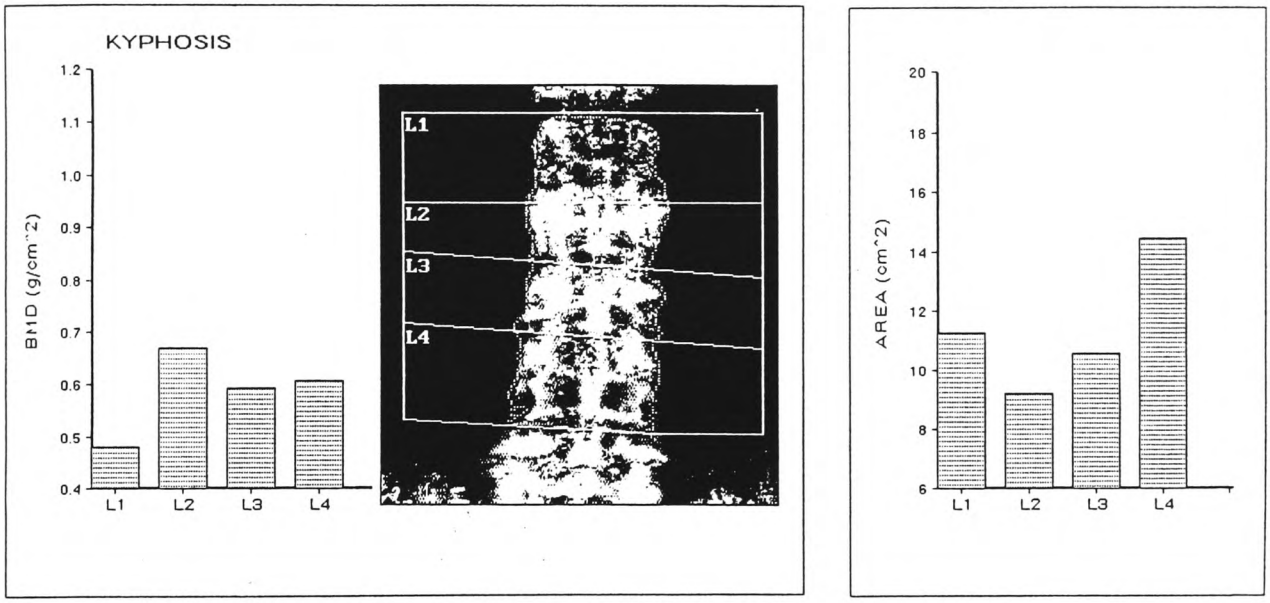


Figure 6.2a Vertebral haemangioma not visible on scan but elevating z score at L3 level and was only detected by performing a lateral radiograph *(fig.6.2b)*.

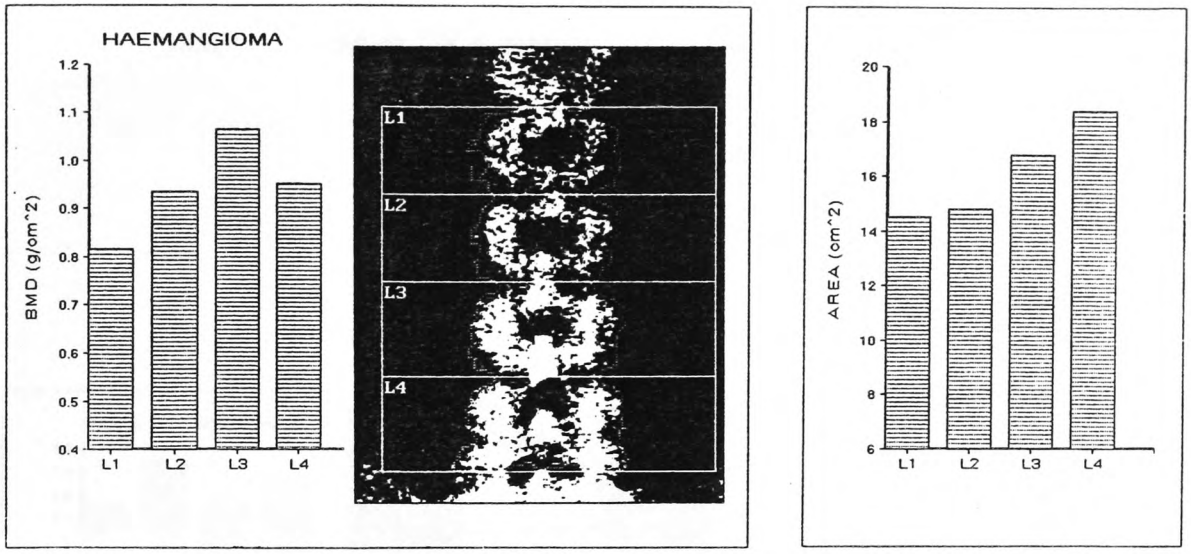


Fig.6.2b Lateral Radiograph of lumbar spine.

Figure 6.3 Paget's Disease of the spine (previously undiagnosed) with BMD values markedly increased (z score 7.3). In Paget's Disease high values of BMD occur often as a generalised or localised increase. Thus a combination of density and vertebral area should be regularly checked in DXA reports.

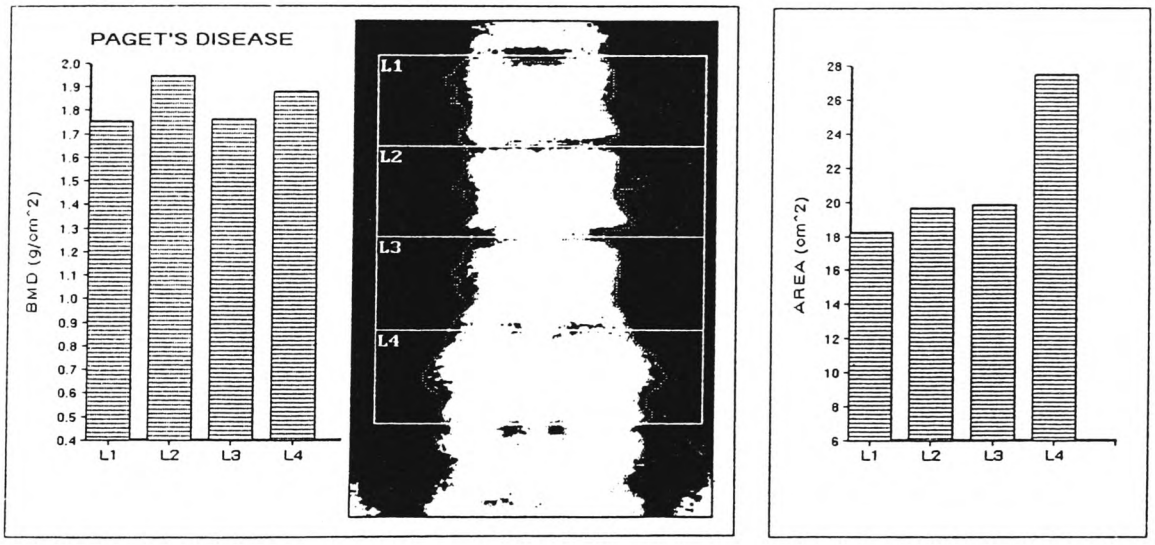


Figure 6.4 Degenerative disease of the spine, wedge fracture at L2, and osteophytes giving higher, erroneous, values of BMD .

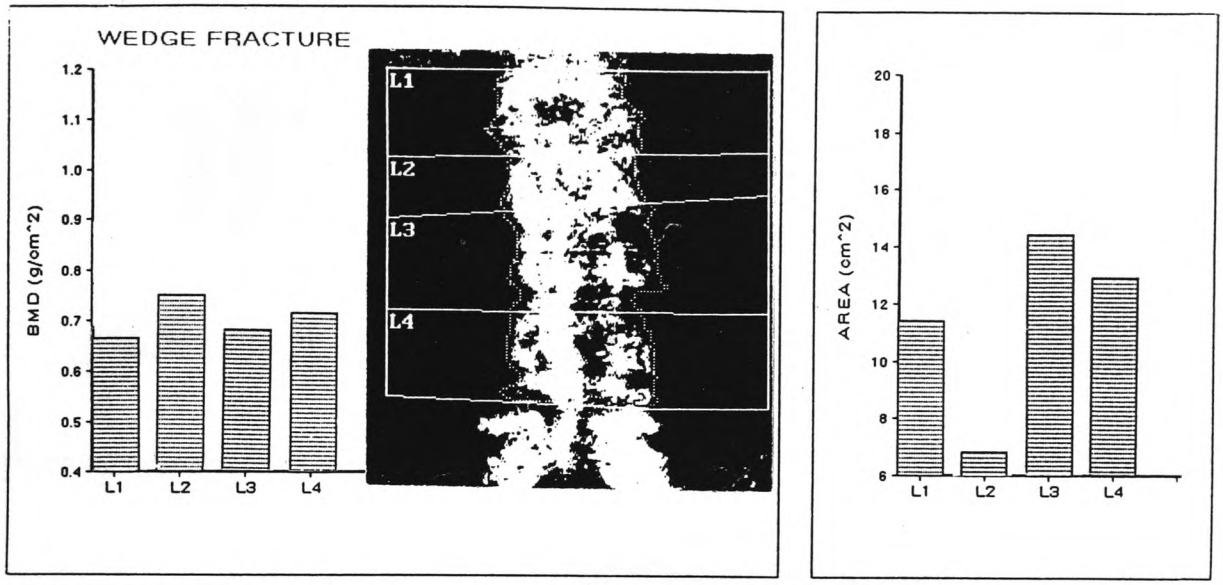


Figure 6.5a Patient with calcified aorta mainly effecting results of L3 and L4 as shown in the radiograph *(fig. 6.5b)*.

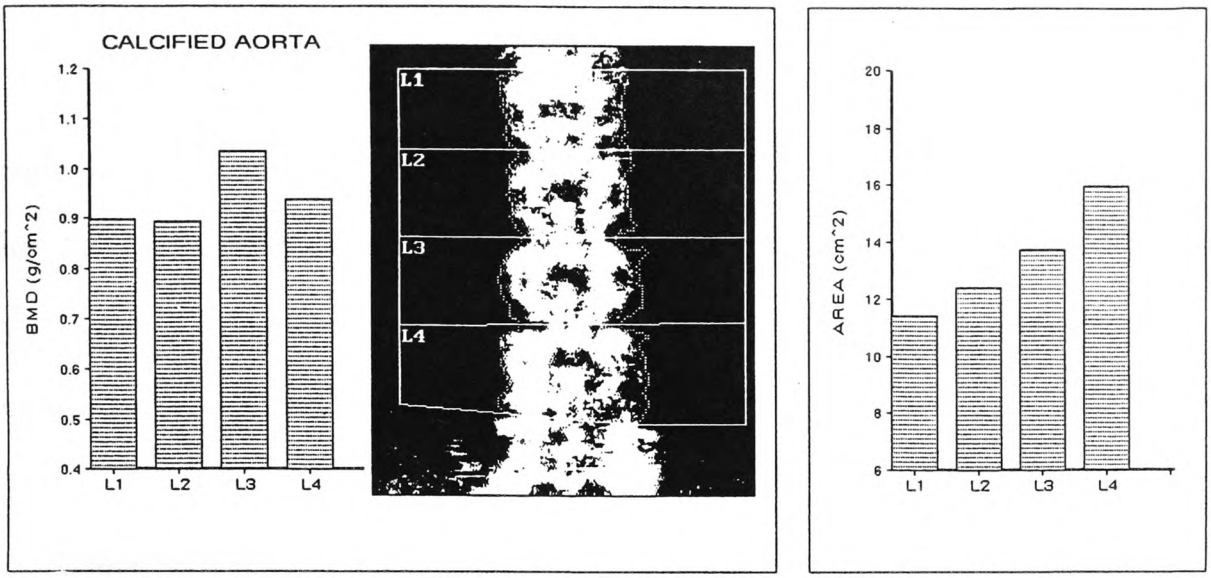
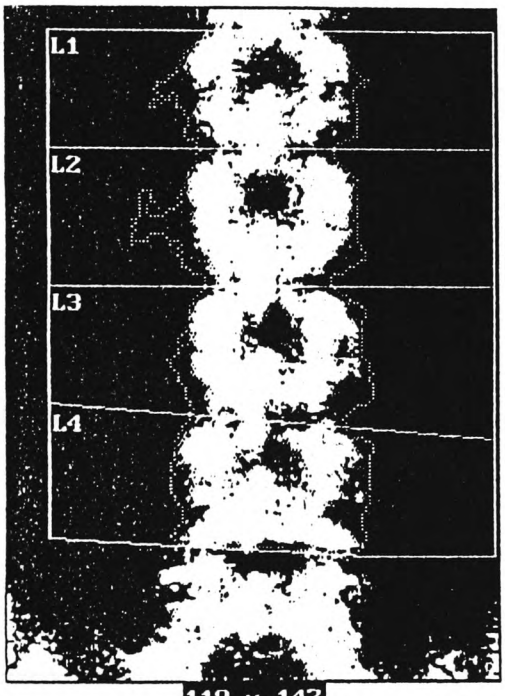


Fig.6.5b Radiograph of lumbar spine.

The scan of the patient shown in *fig. 6.6* shows the result of calcification in the soft tissues and the difficulties in comparisons with future scans when the calcification is not constant in position or quantitatively.

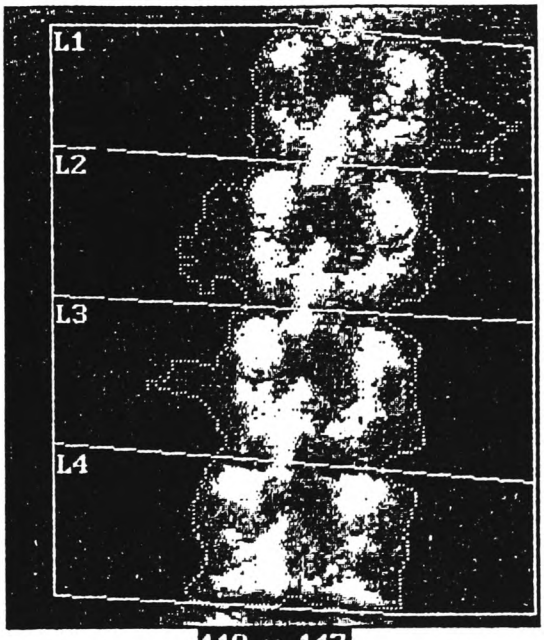
Figure 6.6 Scans of patient with calcification of the soft tissue taken with interval of 1 year. The first scan shows less influence of the calcification than the second scan where L1, L2 and L3 are clearly affected. This patient was subsequently x-rayed and was found to have calcification of the overlying psoas muscle.



Hologic QDR 1000 (S/N 250)

Region	Area (cm2)	BMC (grams)	BMD (gms/cm2)
L1	14.49	15.85	1.094
L2	17.33	19.96	1.151
L3	17.40	21.60	1.242
L4	17.06	21.09	1.236
TOTAL	66.28	78.50	1.184

HOLOGIC



Hologic QDR 1000 (S/N 250)
Lumbar Spine Version 4.26

Region	Area (cm2)	BMC (grams)	BMD (gms/cm2)
L1	16.11	18.19	1.130
L2	18.96	22.05	1.163
L3	18.80	22.25	1.184
L4	17.30	21.64	1.251
TOTAL	71.17	84.15	1.182

HOLOGIC

A further study carried out at this hospital by Dr. Nikos Galanopoulos in 1992 (abstract presented at 1992 Hellenic Rheumatology Conference, Athens) gives further insight into the health of the local Bath population. 203 (107 female, 96 male) volunteers were randomly selected from local G.P.'s patient lists. Each underwent lateral radiography to assess vertebral abnormalities and responded to a questionnaire completed by the same interviewer. (The author's contribution to this study was in the random selection and interviewing of patients). Details of age, weight, height, ethnic group, dairy product consumption, alcohol consumption, medical history, medication and physical activity were recorded.

The incidence of aortic calcification in the peri/post-menopausal female group was found to be 9.5% but was 31% and 79% in 60+ females and 70+ females respectively, higher than reported by other studies (table 20). The incidence of aortic calcification in men is high in the 70+ age group (50%).

Table 20 Incidence of :	**Aortic calcification**	**Osteophytosis-Lumbar Spine**
50-59 years n=80(M+F)	6 (7.5% : 5.3%M,9.5%F)	1 (1.2%)
60-69 years n=73(M+F)	19 (26% : 18.7%M,31%F)	3 (4%)
70+ years n=50(M+F)	32 (64% : 50%M,79%F)	11 (36%)

We found that 28% of the population had calcification of the aorta (50-59+ years, 3%; 60-69+ years, 9%; 70-86+ years, 16%). Of these 28%, 70% also had some other abnormality e.g. osteophytosis, narrowing of the intervertebral spaces, vacuum phenomenon in the intervertebral spaces or spondyloasthesis. 21% had osteophytes in

the lumbar spine region (50 - 59+, 3%; 60 - 69+, 4%; 70 - 86+, 14%). Only 3% of the 70+ group had spondyloasthesis (table 21).

Table 21 % of subjects with abnormal findings on X-ray N=203 107(52.7%)F 96(47.3 %)M

Age	With findings	Dorsal spine only	Lumbar spine only	Both	F	M
50-59years	63.7	39	27	33	74	55
60-69years	65.7	25	25	50	68	62
+70years	86	21	16	63	80	92

Discussion

These studies show that the prevalence of these factors may be far higher locally than had previously been thought for other regions. Selection bias is unlikely as both clinical patients and randomly selected subjects showed the same trend. This raises the question of the validity of "normal data" in the 70+ age group where control studies have not included a lateral spine radiograph as a limiting factor. Calcification of the aorta and osteophtyes attached to the vertebral body in 40% of the 70+ population will inevitably produce higher BMD results than patients without them.

We concluded from Dr. Galanopoulos' results that 70% of our local population had X-ray findings in both lumbar and dorsal spine, particularly in the 70+ years age group. More than 25% had osteophytes in over 3 vertebrae. Also calcification of the aorta is more frequent in the 70+ group. Crush fractures of the spine may lead to an erroneously high BMD result as the quantity of bone mineral is increased in a decreased

volume. Thus scanning in P-A mode will not necessarily pick up this anomaly when comparing results against Z-scores and reference graphs. Patients with curvature of the spine, especially in the lumbar region, will not produce an accurate result for a P-A scan. A distortion of the image occurs and if calcification is also present the vertebral bodies become indistinct. BMD results will be falsely raised. It is important that the operator is aware of possible problems so that e.g. high Z-scores in individual vertebra are investigated. Obviously, if the condition of the patient affects all vertebrae in the scanning area there will often be no indication to the operator that the results are being affected, other than a higher than average BMD. This is a limitation of the system.

The image of the lumbar spine obtained during bone mineral scanning is often of sufficient quality to indicate gross abnormalities before analysis e.g. crush fractures and osteophyte formation. However, DEXA images are intended for quantitative rather than diagnostic purposes. It is now more common for a patient to be referred for densitometry, before a diagnostic radiograph has been obtained, in which case, special care must be taken. The scan operator requires some background knowledge of anatomy and/or radiography in order to identify anomalies and to select consistent levels for analysis when extra ribs or vertebrae are present. A progressive increase in BMD from L1 to L4 level is approximately 10% greater at each level. A sudden increase of 30% in one vertebral level may be caused by clinical abnormality and needs investigation. It is therefore important to analyse individual vertebral results rather than presenting an average value for L1 to L4 vertebrae.

This study showed that undiagnosed conditions may be present in healthy control

subjects which will affect and usually raise the BMD of the spine in P-A projection. This becomes more evident when values obtained by densitometry are compared with a "normal" population graph or as a Z-score. It is thus possible to overlook an osteoporotic spine which appears normal due to an overlying clinical abnormality, especially where there are no supporting lumbar radiographs. Often it is difficult for bone edges to be detected correctly when BMD levels are low, or if there is excessive calcification of the soft tissues in front of the spine or femur. This may be a function of the software employed by the scanner. The edge detection on Hologic machines lead to difficulties in comparisons with future scans. Hologic's algorithms often include a proportion of the transverse processes of the vertebrae and enlarge the area measured, thus reducing the BMD . However, as the processes have mineral values often approaching low level calcification in the soft tissue, this can make an accurate result impossible *(fig.6.6)*.

Misleadingly low BMD results might also arise if a subject has excess adipose deposits, especially if the thickness of fat over the bone is different from that over the soft tissue used for a baseline (Tothill and Pye, 1992). As the manufacturers use different areas of soft tissue for their baselines different errors are introduced.

These results show that measurements of BMD for the older age group of individuals, certainly 70+ years may be inaccurate or misleading to the clinician, with the affects of degenerative disease and osteoporotic fractures masking the true condition of the bone.

Positioning Errors

Lumbar spine

Bad repositioning during lumbar spine studies previously affected the results of reproducibilty studies. However, since the advent of more advanced software allowing analysis grids to be angled to follow the contours of the patient's vertebrae this effect has been minimised. Once patients are in the supine position on the scanner with their legs resting on the foam block they automatically relax into a flattened spine position. Patients with severe back pain can often find lying on a hard bed for any length of time extremely painful and may be unable to maintain a flattened spine, but with decreasing scanning times this problem has largely been eliminated.

Femoral Neck

Introduction

Hip scan reproducibility in successive measurements is not as accurate as with the lumbar spine, largely due to the more complex anatomy of the region and the possibility of positioning errors. This is reflected by the increase in imprecision in hip studies compared to P-A spine (pp 44-46). The subject's leg has to be rotated and held against an angled block. This may not be easy in a patient with hip and / or knee pathology causing restricted movement or excessive pain. Despite the strapping around the angled block provided it is also possible for the leg to rotate slightly as the subject relaxes. This leads to the possibility of precision errors. A small study was undertaken to check if this rotation would affect BMD results.

Methods and Materials

A normal female subject with no hip morphology was used for this study. The subject was positioned with her left femur centrally on the Hologic QDR1000 scanning table to allow aduction and abduction of the hip. The subject was first scanned with the femur rotated against the foam block i.e the standard scanning angle of 20^0 internal rotation. Without repositioning the patient, to reproduce movement due to the subject's femur/tibia alone, scans were repeated at angles of 0^0 rotation, i.e. with foot in upright position, 20^0 external rotation, 40^0 external rotation and 40^0 internal rotation. The angles were measured using a large protractor between the table surface and a vertical line drawn on the subjects foot. The leg was supported throughout by sandbags to prevent movement.

Results

Table 22 shows the resulting BMD values, whilst Table 23 looks at the % change in BMD results when scanning angle of the femur is altered.

Table 22 BMD values(g/cm^2) Left Hip regions at different angles of rotation

Angle of rotation	BMD Neck	BMD Troch	BMD Inter	BMD (g/cm^2) Ward's
20^0 internal	0.758	0.718	1.070	0.633
0^0	0.794	0.722	1.112	0.684
20^0 external	0.804	0.735	1.071	0.638
40^0 external	0.828	0.723	1.036	0.657
40^0 internal	0.779	0.723	1.082	0.672

(Neck=femoral neck Troch=trochanteric region Inter=intertrochanteric region Ward's=Ward's triangle region)

Fig. 6.7 shows the results of BMD of each region versus scanning angle. This shows a significant increase in BMD for almost all readings in each of the regions scanned.

Figure 6.7 The Effect of Variation of Hip Rotation on BMD Result.

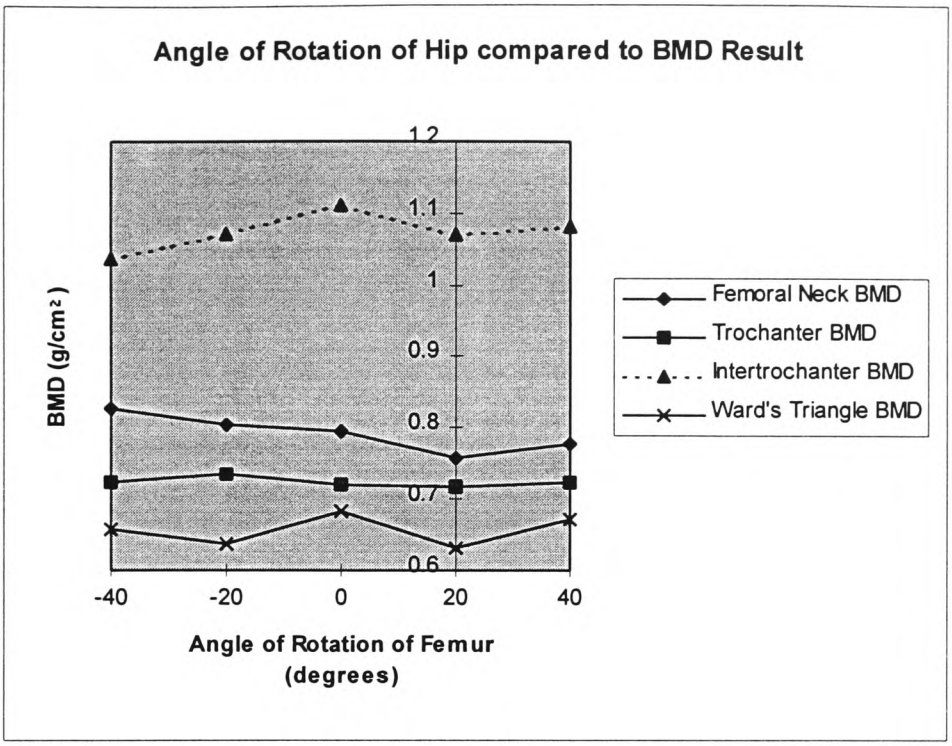


Table 23 % Change in BMD values compared to standard scanning angle.

Angle of rotation	%change Neck	%change Troch	%change Ward's
0^0	+4.75	+0.55	+8.05
20^0 external	+6.06	+2.36	+0.78
40^0 external	+9.23	+0.69	+3.79
40^0 internal	+2.77	+0.69	+6.16

Referring back to precision studies of hip scans (Chapter 3) gives precision figures of between 1.1 and 2.3 for femoral neck region, 1.3-2.8 for trochanteric region and 1.9-5.3 for Ward's triangle region. Even taking the greatest level of precision error this still shows significant differences at the femoral neck region between BMD values obtained with standard scanning angle and those obtained at all erroneous angles measured. Ward's triangle region shows significant error at 0^0 and 40^0 internal rotation.

Discussion

These results show that by altering the angle of rotation of the hip, the surface area to be scanned is altered sufficiently to make a significant difference between values of femoral neck, trochanter, intertrochanter and Ward's triangle.. Therefore, a subject with e.g. deformity of the knee, who would be difficult to position correctly, would not necessarily give an accurate BMD reading unless steps were taken to adjust the position of the femoral neck independantly of the tibia. Strapping on the angled board supplied by Hologic is insufficient in some cases to prevent movement of the femur due to relaxation of the patient or deformities of the ankle or knee. In addition Tothill (1994) showed that fat distribution around the femoral neck is non uniform and potentially open to more errors (also Tothill and Pye, 1992).

Although the information on the hip is very important in assessing osteopenia and fracture risk, there is also a risk of error involved in the measurements obtained especially when considering follow up studies.

We conducted a further study (Knight, 1990) to look at patients with osteoarthritis (OA) of one hip compared to an unaffected hip. Patients with primary OA of the hip rarely sustain fractures of the femoral neck. This infers that bone mineral density in these patients is reasonably high. To check this hypothesis patients who had osteoathritis of the hip were scanned, many of whom also had one normal hip. These results were compared to local control values who were also compared to the American control population.

Methods and Materials

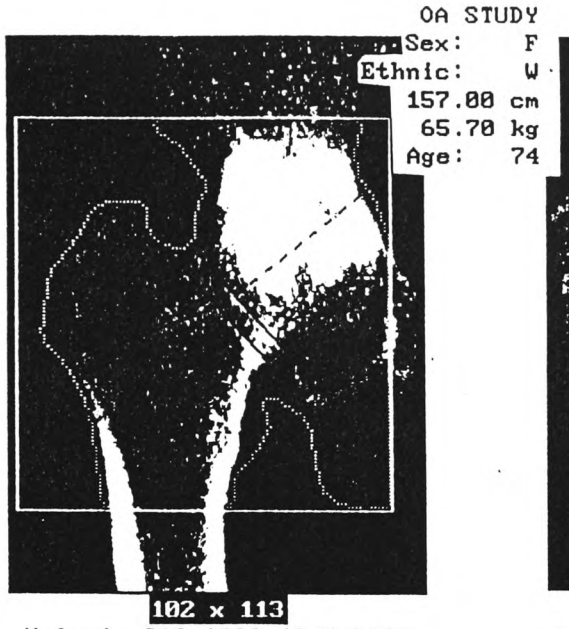
50 patients with OA of the hip were scanned shortly before total hip replacement. 30 female (mean age 68) and 20 male (mean age 66). BMD was measured by Hologic QDR 1000 at femoral neck and Ward's region and results compared with the control data supplied by the manufacturers from an American population.

Ward's region was defined as the 11 x 11 pixel area within the femoral neck with the lowest sampled bone mineral density. In addition 72 normal volunteers were recruited locally (51 female - mean age 51, 21 males - mean age 57) and their BMD values at femoral neck and Ward's region compared to the manufacturer's control values.

Results

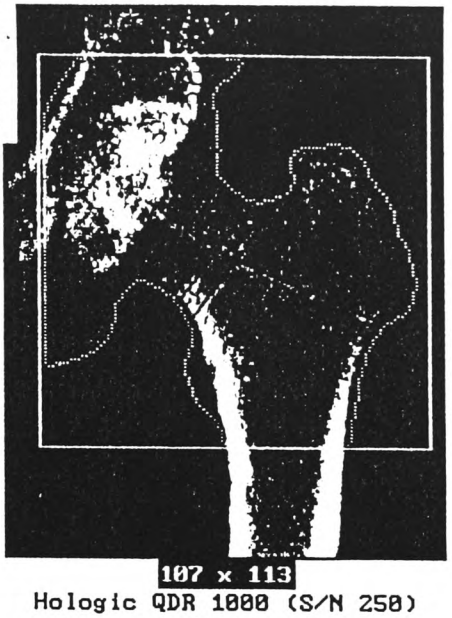
The unaffected hip showed an increased BMD at femoral neck level compared to controls, whilst Ward's region was within normal values for age matched controls *Fig.6.12, 6.13 and 6.14.*

Figure 6.12 Bone Densitometry report comparing OA R hip with normal L hip



Hologic QDR 1000 (S/N 250)
Right Hip

Region	Area (cm2)	BMC (grams)	BMD (gms/cm2)
Neck	2.49	2.97	1.194
Ward's	1.11	0.79	0.711



Hologic QDR 1000 (S/N 250)
Left Hip

Region	Area (cm2)	BMC (grams)	BMD (gms/cm2)
Neck	2.54	2.02	0.796
Ward's	1.11	0.60	0.547

Region	BMD	Z	
Neck	1.194	+5.52	186%
Troch	0.550	-0.06	99%
Inter	1.332	+3.21	151%
TOTAL	1.195	+3.75	160%
Ward's	0.711	+2.62	168%

* Age and sex matched

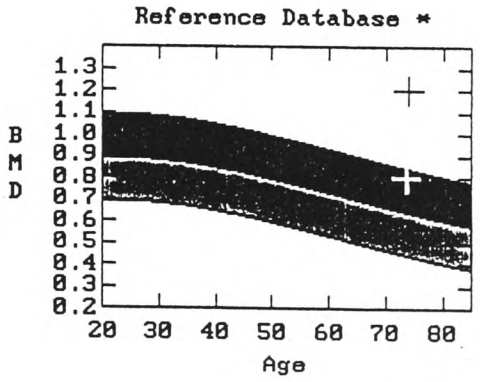
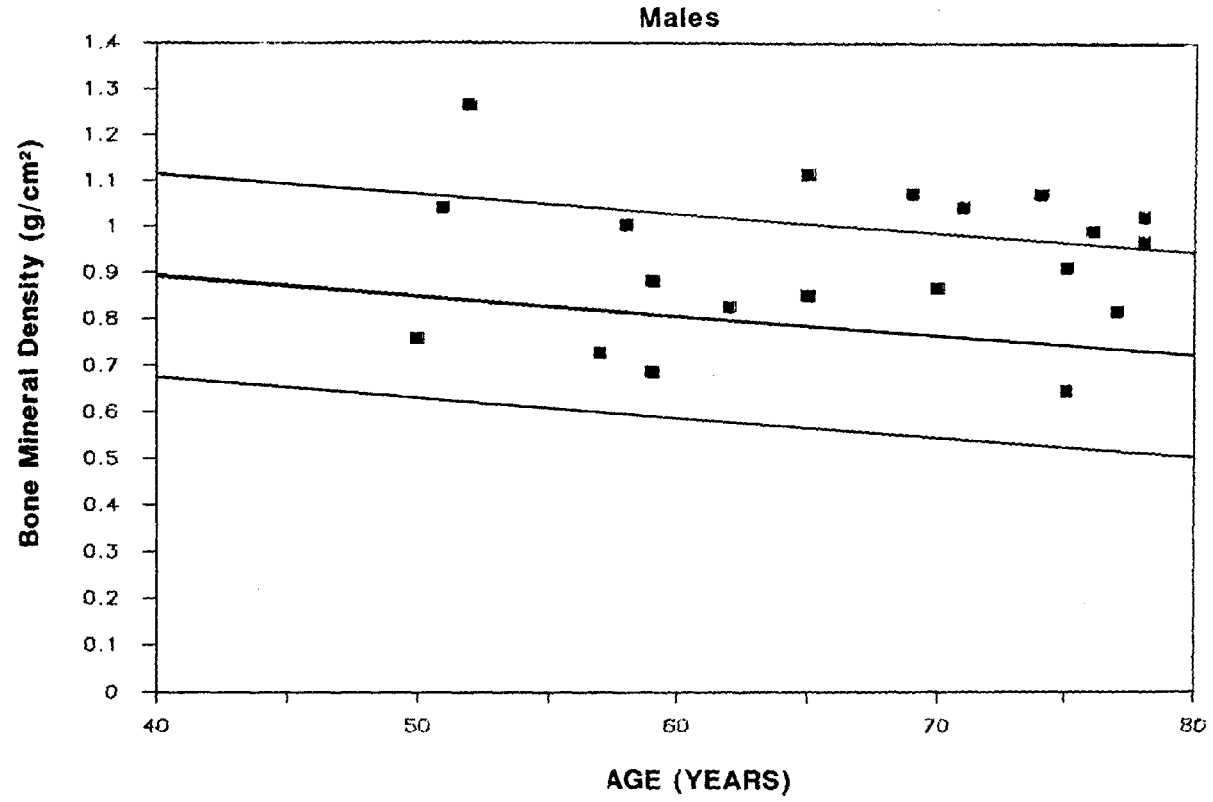


Figure 6.13 BMD of Femoral Neck in Osteoarthritis of the hip.



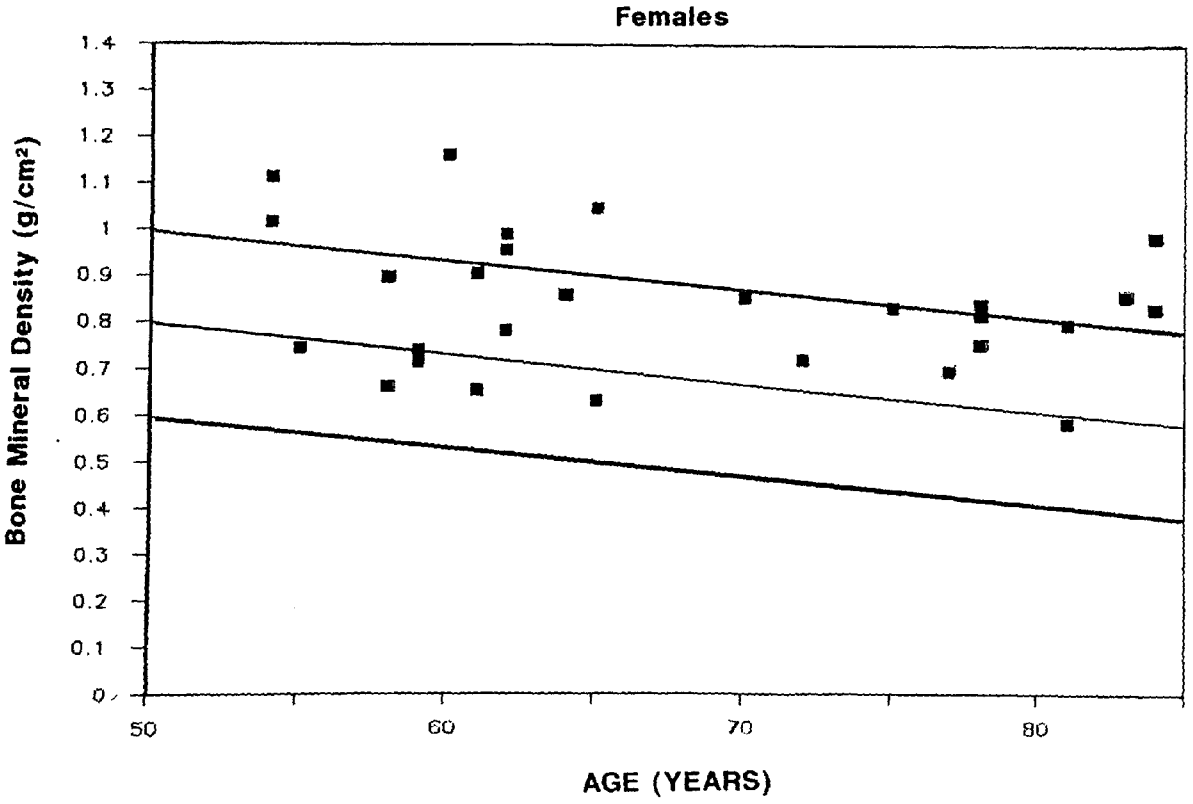


Figure 6.14 BMD of Ward's region to compare BMD in affected and unaffected joints in Osteoarthritis of the hip.

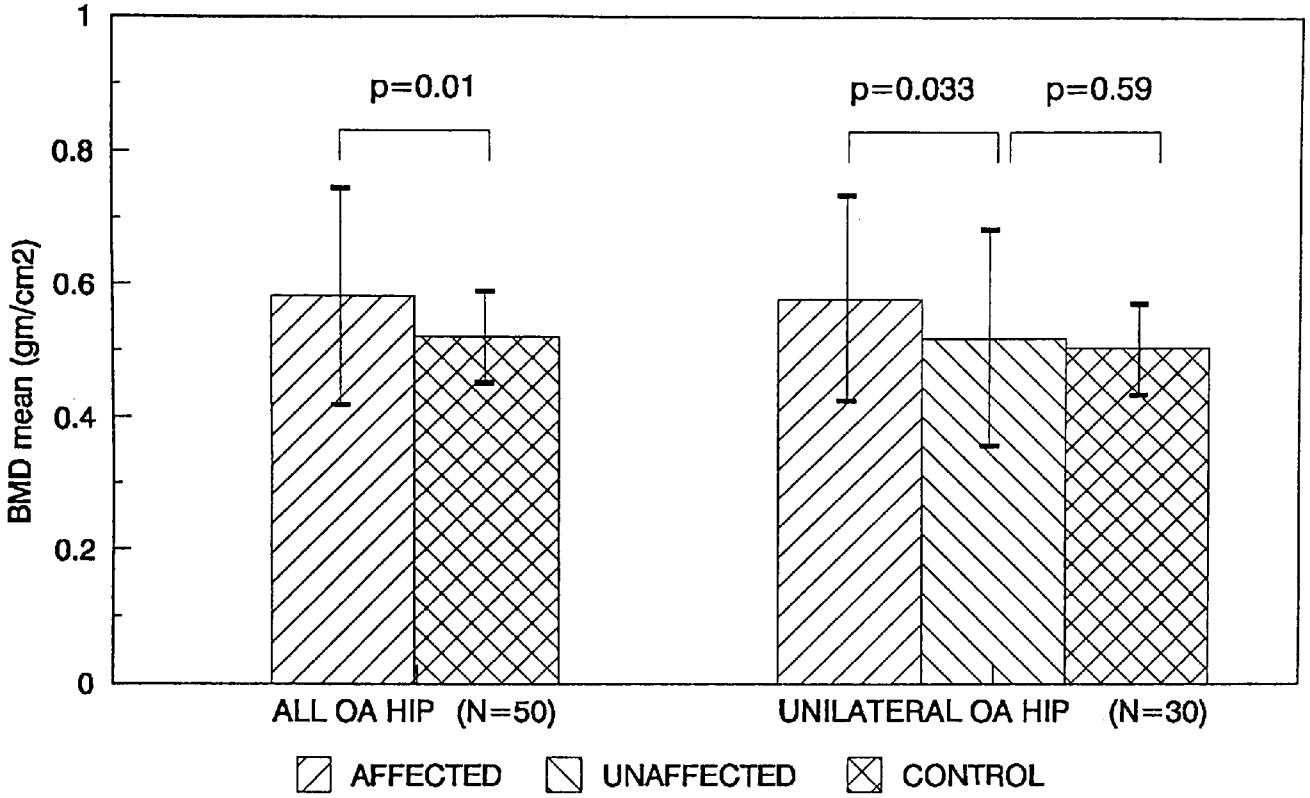
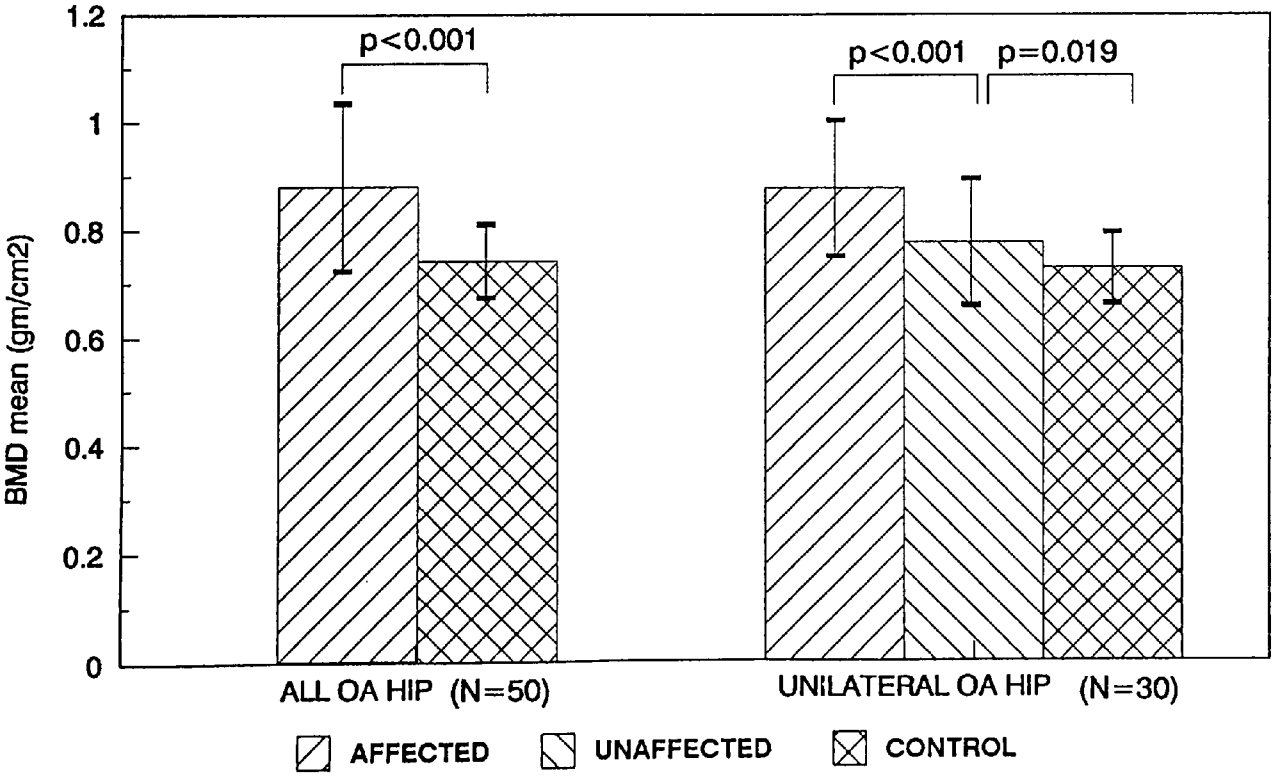


Figure 6.15 BMD of Femoral Neck region to compare BMD in affected and unaffected joints in Osteoarthritis of the hip.



It was found that local controls had similar values of BMD of the femoral neck and Ward's region to the American population values. The BMD results of the OA hips showed an increase in both femoral neck and Ward's region compared to Hologic results. Where only one hip was affected by OA (30 patients) the BMD of this hip was significantly greater than the unaffected hip both at femoral neck and Ward's region.

Discussion

When scanning these patients the resulting scan indicated different rotations of the hip due to the deformity of the condition compared to normal subjects and this had to be taken into consideration when the results were assessed.

Although the information on the hip is very important in assessing osteopenia and fracture risk, there is also a risk of error involved in the measurements obtained especially when considering follow up studies. It has been suggested that BMD measurements of the femur might give more information than spine BMD for lumbar fracture. Griffin (1991) shows that Ward's triangle and femoral neck densities are more able to discriminate controls from osteoporotic subjects than vertebral measurements and postulates that the femur may be a better site than lumbar spine for evaluation of osteoporosis. However, Adams et al (1992) comparison of SPA and dual energy QCT of the spine and DEXA measurements of spine and femoral necks compared to the American reference data supplied concluded that BMD measured by one technique could not be used to predict the BMD by another method in the same or different anatomical site. Clements et al (1993) in one of the first longitudinal studies show results which suggest that measurement at one

site cannot predict rate of change at another site. It has been shown that correlation between right and left femoral neck values is reasonably high. Hall and Heavens (1991) concluded that it is acceptable to study only one hip if consideration is given to the fact that variations do occur.

Measures to reduce errors

Lumbar spine

The latest advance in dual energy absorptiometry is scanning of the spine in lateral projection. This would seem to benefit cases where effects of osteophytes and aortic calcification can be excluded.

The main advantage of lateral scanning is the ability to obtain values of BMD for the vertebral body of the vertebra, excluding the posterior neural arch and vertebral processes. Trabecular bone, as previously mentioned, is more metabolically active with earlier differential loss of mineral than the compact bone, which makes up a thin shell around the greater mass of trabecular bone and the greater part of the neural arch. Thus when BMD is measured in the P-A projection both types of bone are quantified together with any bony calcification over or underlying the spine.

There is evidence that osteoporotic fractures occur first in the vertebral body and distal radius of the arm which is also predominantly trabecular in structure (Riggs & Melton 1983). QCT of the vertebral body also shows greater differences in mineral content between normal and osteoporotic patients than is shown by P-A scanning of the entire

vertebra (Sambrook et al, 1985). Genant (1987) also observed that age related bone loss at the lumbar spine was greater than that assessed by P-A DPA scanning.

Initial results using existing DEXA scanners but repositioning the patient on their side (decubitous position) rather than in the supine position had a number of problems. As the amount of soft tissue through which the energy beam must pass is much greater, so is the attenuation of the beam. This alters the in vivo precision from 1% for P-A scans to 2% for lateral scans (Lunar Corporation DPX scanner). To improve upon this both Lunar and Hologic produced machines with 4 times the photon flux giving 2.4% precision for Lunar DPX-L and 2.8% precision for Hologic 1000 performance 2 (Mazess et al, 1989; Slosman et al, 1990; Mazess et al, 1991).

Beam hardening and scatter contribute to these errors. Correlation between P-A and lateral scanning was shown to be higher in women aged 20-49 years than those over 50 years (Mazess et al,1989). This led to the view that decubitous lateral scanning was only useful in patients over 70 years of age with osteophytes and sclerosis of the vessels. It has also been found that only two vertebrae can be included in results because of the influence of the ribs at L1 level and the iliac crest of the pelvis at L4 level. Some studies maintain that only L3 is reliable, L2 also being influenced by the ribs, whereas others found that the influence is not significant at this level (Slosman et al, 1990) and is largely a matter of correct positioning of the patient's arms.

The Hologic QDR 2000 scanner improved lateral scanning by scanning the patient in supine position for both P-A and lateral scans without repositioning the patient in

between. This is achieved by the rotation of the scanning arm around the bed. Precision errors induced by poor repositioning are substantially reduced. Vertebral identification is determined on the P-A and lateral view simultaneously. Short term precision in vivo has been shown to be 0.59% with no significant difference between values from the QDR 1000 and QDR 2000 (Steiger et al, 1991). The speed of the scan is greater, P-A and lateral scans of the spine can be achieved in less time than taken to scan the P-A spine on the QDR 1000.

There are two major determinants of the fracture risk related to bone mass, peak adult bone mass and post-menopausal rate of bone loss. It has been shown that values of BMC obtained by lateral scanning show a greater rate of bone loss than that measured by P-A scanning. Mazess et al (1989) showed a 43% decrease in BMD on lateral projection compared to 20% for P-A projection. Slosman et al (1990) showed that by comparing results in a group of women aged 20-35 years compared to a group of women aged 60-75 years loss in BMD was 37.6% in lateral projection and 21.5% in P-A projection. For osteoporotic women with known crush fractures it was 52% in lateral and 31% in P-A projection.

Uebelhart et al, (1990) also showed that age related bone loss between 30 and 80 years of age was much higher with lateral (44%) than with P-A (22%) projection , and in osteoporotics was 30%(lateral) compared to 23% (P-A). This is all consistent with the greater loss of trabecular versus compact bone over this age span and the greater influence of artefacts with age. It can also eliminate false negative and false positive indicators of vertebral fracture risk produced by P-A scanning alone.

Software for DEXA machines has been constantly updated and scans have become faster and more automated, reducing error and increasing precision. The Hologic QDR 2000 machine completes AP spine and hip scans in less than 30 seconds and lateral scans in 3-5 minutes. The Hologic QDR 4500 can scan the total body in 3 minutes. Analysis time is also reduced. However, this overlooks the need for intervention by the operator who must be aware of the possible presence of artefacts by visual examination of the scan and assessment of Z-scores. This to some extent negates the added speed of analysis.

Femoral Neck

Femoral Neck Positioning

Norland have designed a device which holds the patient immobile by lifting the femurs away from the scanning table as it rotates them to the required angle. This supports the weight of the patient's legs and removes the need for the subject to hold their hip under tension voluntarily as with the Hologic and Lunar strapping systems.

CONCLUSIONS

The examination of the available methods of bone mineral measurement and their limitations identifies dual energy X-ray absorptiometry as the most effective technique. Over the last eight years this technique has progressed from slow, radioisotope powered to a rapid dual X-ray fan beam technique requiring only minutes, or seconds to scan the same area. Precision has improved markedly with each upgrade of machine and software, particularly in the hip region and appears to be similar for the different manufacturers.

Conditions which affect the lumbar spine or hip region occur in previously screened 'normal' populations of all age groups in addition to clinical cases and the older population. The need for adequately trained, alert personnel to perform these scans, identify anomalies and take corrective measures is paramount in order to minimise the effects of artefacts and misleading data. This may mean that further scans need to be recorded from other sites or that radiographic images are required to compare with DEXA scan images before the patient leaves the hospital. Improvements in technology have helped. The use of lateral scans of the lumbar spine, where abnormality is suspected, limits the affect of calcification in the spinal vessels or osteophytes etc..

Positioning of patients, particularly for hip scans, is still open to error in allowing movement on relaxation of the patient and current methods of positioning the leg by Hologic and Lunar leave room for error and should be addressed.

The bone mineral density reports carry a large amount of information which may be open to misinterpretation by clinicians. Comparisons of results against the reference range is a vital part of diagnosis of osteoporosis. Numerous reference ranges are in use across this country alone, leaving clinicians to conclude differing diagnoses for the same BMD result and consequently differing treatments for the osteoporosis candidate. There is always the remaining question of whether local populations agree or disagree with the manufacturer's reference data. WHO standards require a minimum of 116 subjects per decade to achieve 95% confidence that the BMD reference mean will be within 2% of the true mean. This is beyond the scope of many clinical units where scanning time is predominantly required for patients and collaboration between centres would seem the most viable option. However, ethical comittees now require that local control data be acquired. This will only produce a small sample of the population and all that is possible is to compare this to the manufacturer's data to see if there is any significant difference. Our study, although small, shows strong trends in the elderly population which are supported by larger studies on populations within a 60 mile radius (Petley et al,1996).

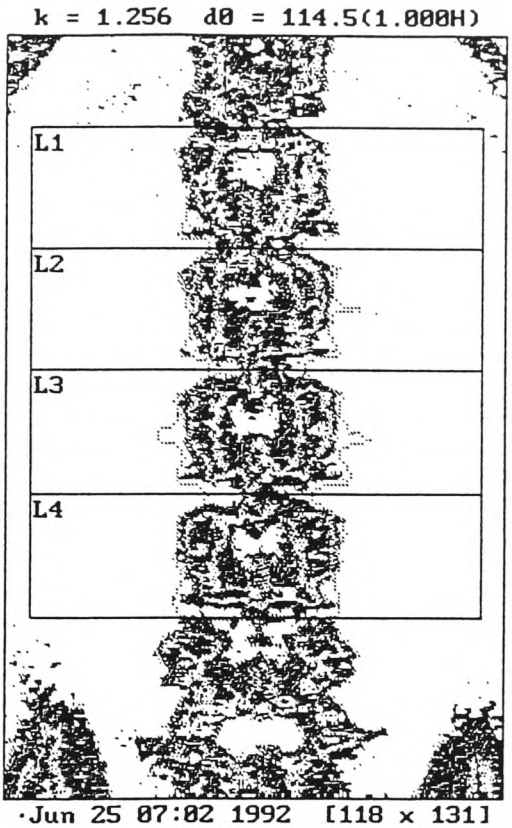
These are cross-sectional studies. Ideally logitudinal measurements should make up the reference database but the lifetime of the technique is insufficient at present. In the meantime, while critical users of the DEXA technique express their caution over the literal interpretation of single measurements, many clinicians continue to use them in blind acceptance. Further work needs to be carried out on the Bath population to validate the trends of high BMD values in the lumbar spine and hip of 70+ year olds. A standard UK reference population should be achievable within the next few years.

The temptation for a busy non-specialist clinic to use DEXA and produce the "automatic report" without question is now evident. With the increasing financial burden on the National Health Service, a number of centres have embarked upon DEXA for reasons which include that of financial income. The national publicity on osteoporosis, especially that directed at perimenopausal women, is creating a great demand for densitometry. Only more research into the critical use of the technique and its interpretation will keep this growing situation in perspective in the UK. There is no doubt that the DEXA technique has opened up the whole prospect of quantifying bone mineral content in-vivo. This is spurred on by the vested interests of the pharmaceutical industry who are working to obtain a large market in the treatment of osteoporosis. Many of the first DEXA machines installed in the UK were provided by the pharmaceutical industry for clinical studies. The necessary standards for cross calibration of machines and the interpretation of data are still being debated, although many pharmaceutical studies are in progress , and some are completed.

Software developments by the major manufacturers have been significant. However, there remains a need for well trained alert operators and users of DEXA to minimise the effects of artefacts and misleading data.

Appendix

Appendix 1(a) : Hologic QDR 1000 Lumbar Spine Report



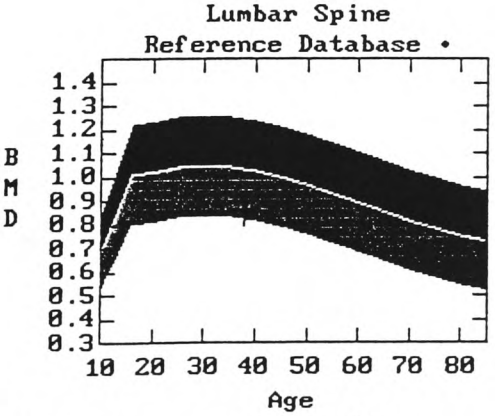
Henry Ford Hospital

A07148816 Thu Jul 14 14:57 1988
Name: ANAYAN
Comment: CROSSOVER STUDY
I.D.: NP DETROIT Sex: F
S.S.#: - - Ethnic: I
ZIP Code: Height:5' 3"
Scan Code: LS Weight: 139
BirthDate: 08/21/50 Age: 37
Physician:

TOTAL BMD CV FOR L1 - L4 1.0%

C.F. 0.999 1.049 1.000

Region	Area (cm^2)	BMC (grams)	BMD (gms/cm^2)
L1	10.75	8.30	0.772
L2	11.25	9.57	0.851
L3	13.11	11.41	0.870
L4	13.04	11.81	0.906
TOTAL	48.15	41.09	0.853



BMD(L1-L4) = 0.853 g/cm^2

Region	BMD	T(30.0)		Z	
L1	0.772	-1.39	83%	-1.26	85%
L2	0.851	-1.61	83%	-1.47	84%
L3	0.870	-1.95	80%	-1.80	81%
L4	0.906	-1.91	81%	-1.76	82%
L1-L4	0.853	-1.76	82%	-1.62	83%

◆ Age and sex matched
T = peak bone mass
Z = age matched TK 11/04/91

HOLOGIC

Henry Ford Hospital

A07148816 Thu Jul 14 14:57 1988
Name: ANAYAN
Comment:
I.D.: NP DETROIT Sex: F
S.S.#: - - Ethnic: I
ZIP Code: Height:5' 3"
Scan Code: LS Weight: 139
BirthDate: 08/21/50 Age: 37
Physician:

Physician Comment:

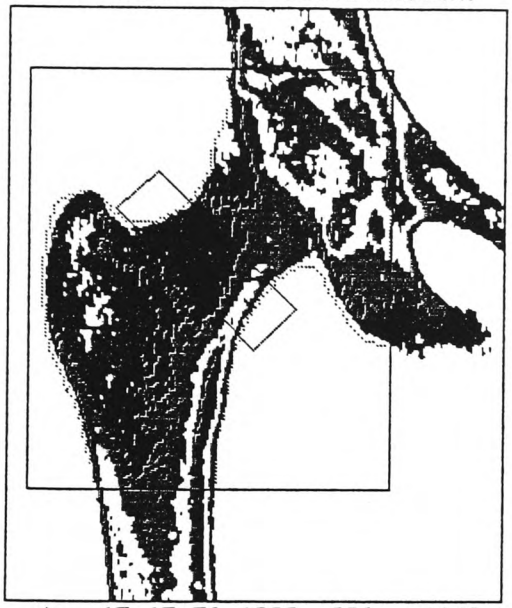
Technique	Good Fair Marginal Uninterpretable
Z Score	Expected Bone Loss Borderline More than Expected
T Score	No Osteopenia Borderline Osteopenia
Other Factors:	Scoliosis Compression FX Osteo-Arthritis Calcif. Laminectomy Other

HOLOGIC

Appendix 1(b) : Hologic QDR 1000 Femoral Neck Report

HOLOGIC

k = 1.220 d0 = 115.2(1.000H)



·Apr 15 15:56 1992 [96 x 114]
Hologic QDR-2000 (S/N 2001)
Right Hip V4.44

A0228912B Thu Feb 28 15:48 1991
Name: 2000 - Carolyn HIP
Comment:
I.D.: Sex: F
S.S.#: - - Ethnic: C
ZIP Code: Height:5' 6"
Scan Code: Weight: 137
BirthDate: 07/19/44 Age: 46
Physician:

C.F. 1.005 1.073 1.000

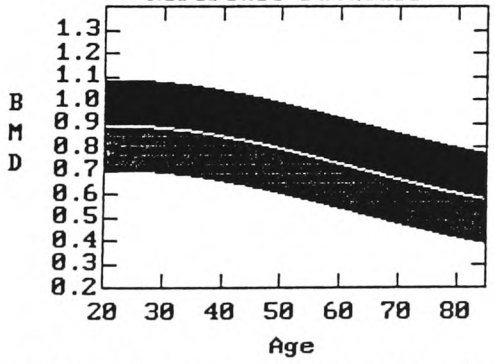
Region	Area (cm^2)	BMC (grams)	BMD (gms/cm^2)
Neck	5.43	3.47	0.639
Troch	12.72	7.46	0.586
Inter	15.61	13.92	0.892
TOTAL	33.76	24.85	0.736
Ward's	1.09	0.53	0.488

Midline (90,120)-(20, 52)
Neck 53 x 16 at [-26, 10]
Troch 1 x 49 at [0, 0]
Ward's 11 x 11 at [-4, 5]

HOLOGIC

HOLOGIC

Right Hip
Reference Database •



A0228912B Thu Feb 28 15:48 1991
Name: 2000 - Carolyn HIP
Comment:
I.D.: Sex: F
S.S.#: - - Ethnic: C
ZIP Code: Height:5' 6"
Scan Code: Weight: 137
BirthDate: 07/19/44 Age: 46
Physician:

Physician Comment:

Technique: Good Fair Marginal
Uninterpretable
Expected Bone Loss
Borderline
More than Expected

T Score: No Osteopenia Borderline
Osteopenia

Other Factors: Osteo-Arthritis
Calcif.
Other

BMD(NeckTrochInterWard's[R]) = 0.728 g/Z Score

Region	BMD	T	Z
Neck	0.639	-2.55 71% (22.0)	-1.77 78%
Troch	0.586	-1.51 81% (30.0)	-1.14 85%
Inter	0.892	-1.83 78% (29.0)	-1.47 81%
TOTAL	0.736	-1.99 76% (28.0)	-1.59 79%
Ward's	0.488	-2.80 61% (20.0)	-1.40 76%

• Age and sex matched
T = peak bone mass
Z = age matched TK 10/25/91

HOLOGIC

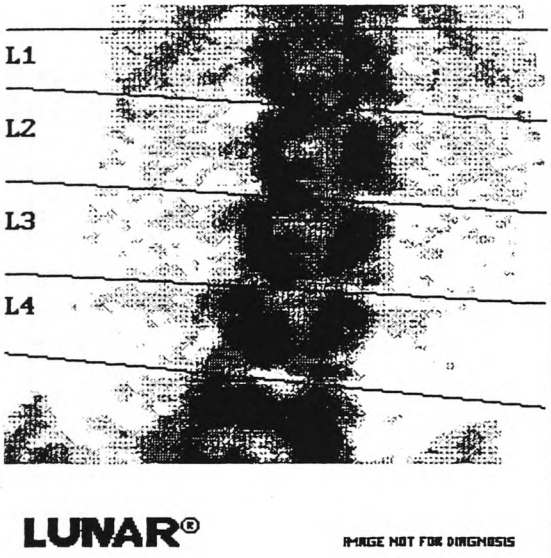
Appendix 1(c) : Lunar DPX Lumbar Spine Report (i)

AP SPINE RESULTS
LUNAR CORPORATION

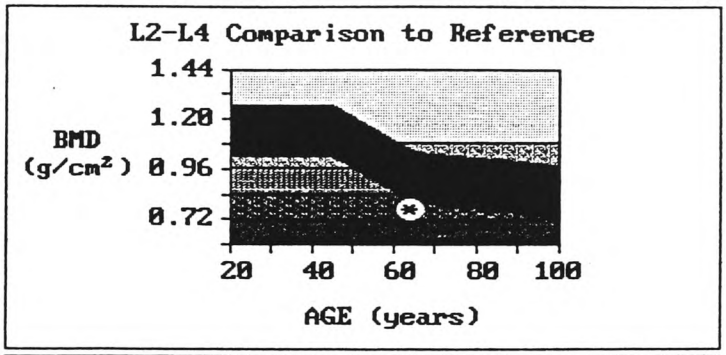
313 W. BELTLINE HWY., MADISON, WI 53713

PATIENT ID: Brinkman
NAME: Brinkman, Betty

SCAN: 3.1 03
ANALYSIS: 1.3 26.06.92



ID: Brinkman, Betty SCAN DATE: 05.03.90



L2-L4 BMD (g/cm²)[1]	0.768 ± 0.01
L2-L4 % Young Adult[2]	64 ± 3
L2-L4 % Age Matched[3]	83 ± 3
L2-L4 Osteoporotic Centile	66

Age (years).....	64	Large Standard.....	275.61	Scan Mode.....	Medium
Sex.....	Female	Medium Standard.....	204.71	Scan Type.....	DPX
Weight (Kg).....	49.1	Small Standard.....	146.12	Collimation (mm).....	1.68
Height (cm).....	150	Low keV Air (cps)...	717930	Sample Size (mm).....	1.2x1.2
Ethnic.....	White	High keV Air (cps)..	445474	Current (uA).....	750
System.....	6118	Rvalue (%Fat).....	1.365(13.5)		

REGION	BMD[1] g/cm²	Young Adult[2] %	Young Adult[2] Z	Age Matched[3] %	Age Matched[3] Z
L1	0.717	63	-3.44	84	-1.17
L2	0.708	59	-4.10	76	-1.83
L3	0.790	66	-3.41	85	-1.14
L4	0.797	66	-3.36	86	-1.08
L1-L2	0.712	62	-3.65	81	-1.38
L1-L3	0.741	63	-3.57	83	-1.30
L1-L4	0.757	64	-3.52	83	-1.25
L2-L3	0.751	63	-3.74	81	-1.47
L2-L4	0.768	64	-3.60	83	-1.33
L3-L4	0.794	66	-3.38	86	-1.11

1 - See appendix E on precision and accuracy. Statistically 68% of repeat scans will fall within 1 SD.

2 - USA AP Spine Reference Population, Ages 20-45. See Appendices.

3 - Matched for Age, Weight(males 50-100kg; females 35-80kg), Ethnic.

Appendix 1(d) : Lunar DPX Lumbar spine report (ii)

AP SPINE RESULTS
LUNAR CORPORATION

313 W. BELTLINE HWY., MADISON, WI 53713

PATIENT ID: Brinkman
NAME: Brinkman, Betty

SCAN: 3.1 03
ANALYSIS: 1.3 26.06.92

ANCILLARY SPINE RESULTS**

Region of Interest	BMC (grams)	Area (cm^2)	Width (cm)	Height (cm)	BMC/W (g/cm)	Volumetric Density[1]
L1	5.84	8.15	4.53	1.80	1.29	41
L2	6.67	9.42	3.02	3.12	2.21	39
L3	8.23	10.42	3.34	3.12	2.47	56
L4	8.93	11.20	4.24	2.64	2.11	57
L1-L2	12.51	17.57	3.57	4.92	3.50	40
L1-L3	20.74	27.99	3.48	8.04	5.96	46
L1-L4	29.67	39.18	3.67	10.68	8.09	49
L2-L3	14.90	19.84	3.18	6.24	4.69	48
L2-L4	23.83	31.04	3.50	8.88	6.82	51
L3-L4	17.16	21.61	3.75	5.76	4.57	57

Z-SCORE FOR VERTEBRAL HEIGHT (L2-L4)

Compared to young adult: Z = -3.04
Adjusted for stature: Z = -2.04

Values apply to adults > 20 years; Z < -1 is associated with osteoporosis.

**Ancillary results for research purposes, not clinical use.
The methodologic error on individual vertebra will be higher than on L2-L4.
See appendix E on methodologic errors.

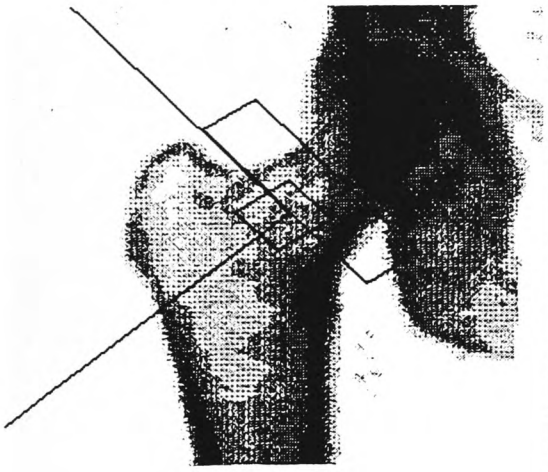
1 Mazess, et al., 1991, Calc. Tiss. Intl., 48:380-386.

Appendix 1(e) : Lunar DPX Femoral Neck Report

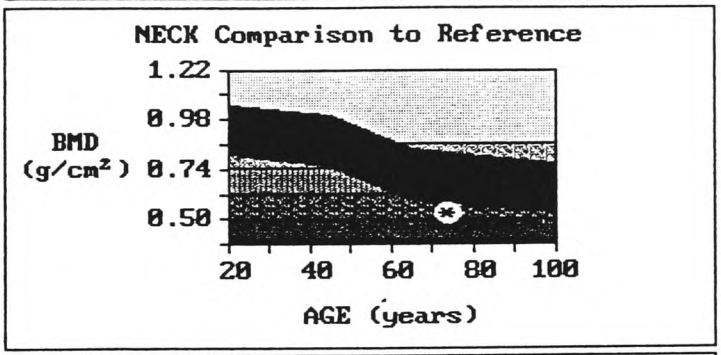
FEMUR RESULTS
LUNAR CORPORATION
313 W. BELTLINE HWY., MADISON, WI 53713

PATIENT ID: Meyer
NAME: Meyer, Ellen

SCAN: 1.7 10
ANALYSIS: 1.3 26.06.92



ID: Meyer, Ellen SCAN DATE: 11.10.88



NECK BMD (g/cm²)[1]	0.534 ± 0.02
NECK % Young Adult[2]	54 ± 3
NECK % Age Matched[3]	77 ± 3
NECK Osteoporotic Centile	70

Age (years).....	74	Large Standard.....	276.60	Scan Mode.....	Medium
Sex.....	Female	Medium Standard.....	207.12	Scan Type.....	DPX
Weight (Kg).....	39.0	Small Standard.....	148.01	Collimation (mm).....	1.68
Height (cm).....	152	Low keV Air (cps)...	646977	Sample Size (mm).....	1.2x1.2
Ethnic.....	White	High keV Air (cps)..	397540	Region height (mm)...	60.0
System.....	6056	Rvalue (%Fat).....	1.387(4.6)	Region width (mm)....	15.0
Side.....	Right	Current (uA).....	750	Region angle (deg)...	52

NECK	: BMC[5] (grams) =	2.52	AREA[5] (cm²) =	4.73
WARDS	: BMC[5] (grams) =	0.86	AREA[5] (cm²) =	2.48
TROCH	: BMC[5] (grams) =	0.69	AREA[5] (cm²) =	2.06

REGION	BMD[1] g/cm²	Young Adult[2] %	Young Adult[2] Z	Age Matched[3] %	Age Matched[3] Z
NECK	0.534	54	-3.72	77	-1.34
WARDS	0.347	38	-4.33	63	-1.60
TROCH	0.337	43	-4.12	56	-2.42

1 - See appendix E on precision and accuracy. Statistically 68% of repeat scans will fall within 1 SD.

2 - USA Femur Reference Population, Ages 20-45. See Appendices.

3 - Matched for Age, Weight(males 50-100kg; females 35-80kg), Ethnic.

5 - Results for research purposes, not clinical use.

Appendix 1(f) : Norland XR-26 Lumbar Spine Report

SABRE SCIENTIFIA LTD, PINGEMEAD HOUSE, SMALLMEAD ROAD,PINGEWOOD,
READING, Tel: (0734) 311811 Fax: (0734) 314145

Name	SPINE HEALTHY FEMALE	*Ethnic*	Cauc.
ID	SHF1 1	*Height*	5'6"
Age	42 *Sex* Female	*Weight*	158

L H AP Spine 07/25/89 Sequence 1

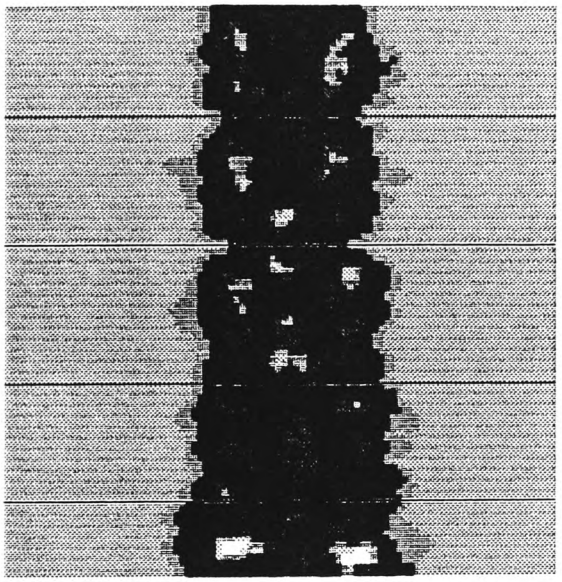
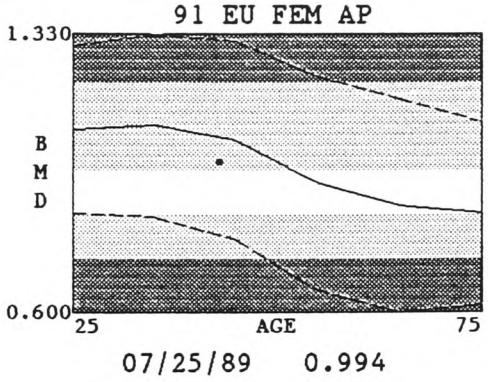


Image not for diagnostic purposes.



% Young Ref.	91.6
T - Score	-0.83
% Age Matched	93.9
Z - Score	-0.51

	BMD g/cm^2	BMC g	LENGTH cm
L2	1.009	14.351	3.30
L3	1.028	16.967	3.60
L4	0.942	14.329	3.00
L2 - L4	0.994	45.647	9.90

CVs for L2-L4 BMD: 1.0 BMC: 1.5 See Operator's Manual for other CVs.
1.5 x1.5 mm, 60.0 mm/s, 13.95 cm Rev. 1.0.1 / 1.1.3 Calib. 07/25/89

COMMENTS

Appendix 1(g) : Norland XR-26 Lumbar Spine detailed results.

SABRE SCIENTIFIA LTD, PINGEMEAD HOUSE, SMALLMEAD ROAD,PINGEWOOD,
READING, Tel: (0734) 311811 Fax: (0734) 314145

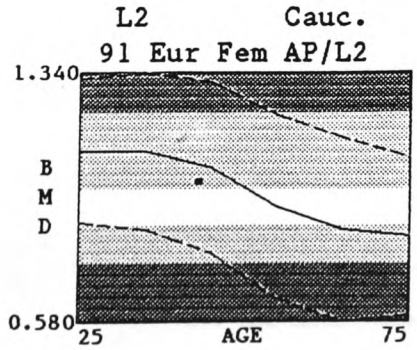
Name	**SPINE HEALTHY FEMALE**		*ID*	SHF1	1
Address	100 Star Ave.		*Ethnic*	Cauc.	
	Tjitjerkeradeel		*Age*	42	
	9834 BM		*Menoage*		
Telephone	*days* 221-56789	*eves*	*Sex*	Female	
History	Simple tibia fracture		*Height*	5'6"	
	at 23		*Weight*	158	
Treatment	none		*Armspan*	1.68	
Medications	Takes the pil				
Comments	Follow up scan Oct. 1990				
	+ whole body				

SCAN INFORMATION

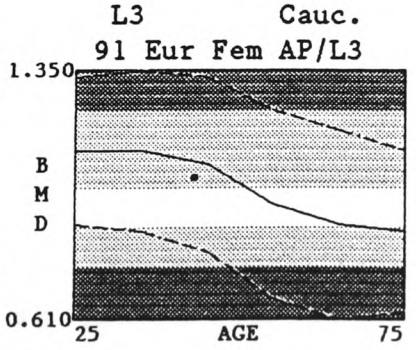
Type	AP Spine			
Scan Date-Seq	07/25/89	1	*Resolution*	1.5 x 1.5 mm
Analysis Date	09/06/91		*Speed*	60.0 mm/s
Calibration Date	07/25/89		*Width*	13.95 cm
Technician	B. MORGAN		*Host/Scanner*	1.0.1 / 1.1.3
Physician			*Analysis Revision*	2.3.0

DETAILED RESULTS

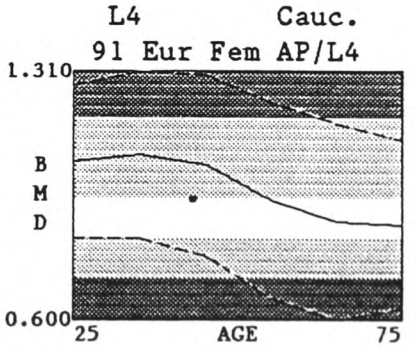
	BMD g/cm²	BMC g	AREA cm²	LENGTH cm	WIDTH cm	LSTM g	FAT MASS g
L2	1.009	14.351	14.23	3.30	13.95		
L3	1.028	16.967	16.50	3.60	13.95		
L4	0.942	14.329	15.21	3.00	13.95		
L2 - L4	**0.994**	**45.647**	**45.94**	**9.90**	**13.95**		



% Young Ref.	91.7
T - Score	-0.83
% Age Matched	95.1
Z - Score	-0.40



% Young Ref.	92.6
T - Score	-0.74
% Age Matched	95.4
Z - Score	-0.39



% Young Ref.	88.9
T - Score	-1.07
% Age Matched	90.0
Z - Score	-0.82

Appendix 1(h) : Norland XR-26 Femoral Neck Report

SABRE SCIENTIFIA LTD, PINGEMEAD HOUSE, SMALLMEAD ROAD,PINGEWOOD,
READING, Tel: (0734) 311811 Fax: (0734) 314145

Name	LEFT HIP (NEW) FEMALE		*Ethnic* Cauc.
ID	LHNF 1		*Height*
Age	38	*Sex* Female	*Weight*

L H Left Hip 01/13/92 Sequence 1

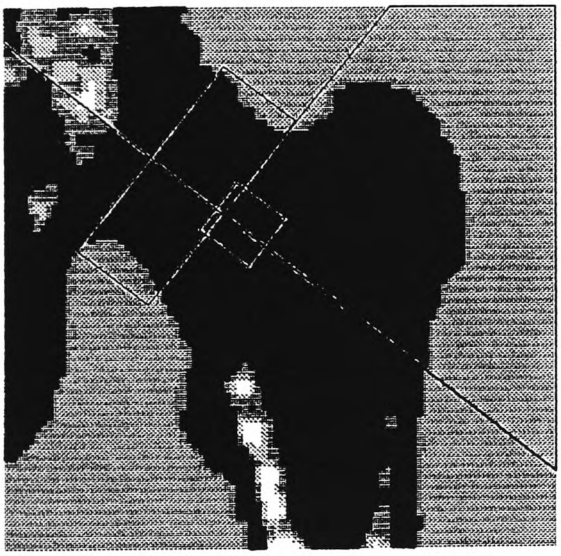
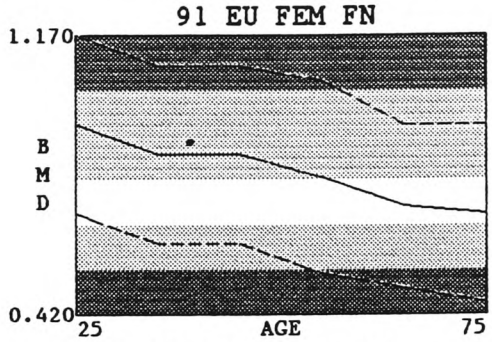


Image not for diagnostic purposes.



% Young Ref.	98.2
T - Score	-0.13
% Age Matched	104.0
Z - Score	0.28

	BMD g/cm²	BMC g	LENGTH cm
Fem Neck	**0.884**	**4.151**	**1.50**
Troch	0.800	8.188	
Wards Tri	0.661	0.661	1.00

CVs for Neck BMD: 2.5 BMC: 2.0 See Operator's Manual for other CVs.
1.0 x1.0 mm, 45.0 mm/s, 9.00 cm Rev. 2.3.0d/ 1.3.0 Calib. 01/10/92

COMMENTS four seq. scans on second day
Fem. neck: manual
Wards: initial only

Appendix 1(i) : Norland XR-26 Femoral Neck detailed results.

SABRE SCIENTIFIA LTD, PINGEMEAD HOUSE, SMALLMEAD ROAD,PINGEWOOD,
READING, Tel: (0734) 311811 Fax: (0734) 314145

Name	LEFT HIP (NEW) FEMALE		*ID*	LHNF	1
Address			*Ethnic*	Cauc.	
			Age	38	
			Menoage		
Telephone	*days*	*eves*	*Sex*	Female	
History			*Height*		
			Weight		
Treatment			*Armspan*		

Medications

Comments

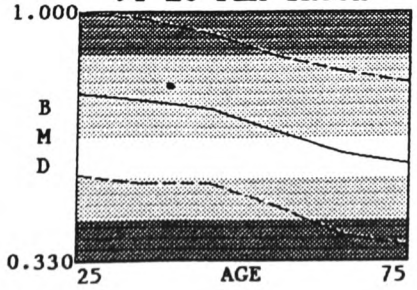
SCAN INFORMATION

Type	Left Hip			
Scan Date-Seq	01/13/92	1	*Resolution*	1.0 x 1.0 mm
Analysis Date	01/24/92		*Speed*	45.0 mm/s
Calibration Date	01/10/92		*Width*	9.00 cm
Technician	TV Sanchez		*Host/Scanner*	2.3.0d/ 1.3.0
Physician	M Grman		*Analysis Revision*	2.3.0e

DETAILED RESULTS

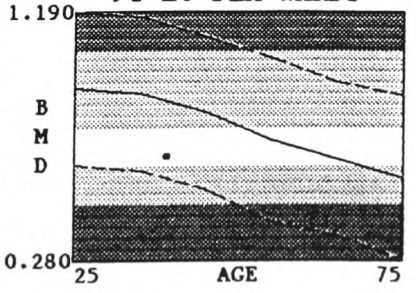
	BMD g/cm²	BMC g	AREA cm²	LENGTH cm	WIDTH cm	LSTM g	FAT MASS g
Fem Neck	**0.884**	**4.151**	**4.70**	**1.50**			
Troch	0.800	8.188	10.23				
Wards Tri	0.661	0.661	1.00	1.00	1.00		

Troch CAUC.
91 EU FEM TROCH



% Young Ref.	103.9
T - Score	0.28
% Age Matched	106.4
Z - Score	0.45

Wards Tri CAUC.
91 EU FEM WARDS



% Young Ref.	73.5
T - Score	-1.71
% Age Matched	76.7
Z - Score	-1.44

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